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Growth

ON THE DISTRIBUTION AND GROWTH OF INTELLIGENCE*

From the Psychological Laboratory of the University of Stellenbosch
South Africa

R. W. Wilcocks

General Description of Test Used

The present article is intended as a contribution to the question of the distribution and growth of intelligence as determined by means of an intelligence test. The test used was the South African Group Test of Intelligence[1] for children 120 to 192 months old. It is of the so-called "verbal" type, and the whole battery consists of seven tests. These are: (1) a classification test (20 items), (2) an analogies test (30 items), (3) a number series completion tests (20 items), (4) a story completion test (25 items), (5) a "following directions" test[2] (20 items), (6) a same-opposite test (40 items), and (7) a "geometrical" test[3] (20 items). There are four equivalent forms of the battery. A suitable fixed time limit is given to each test in the battery, and the method of application has been fully standardized.[4] In finding the total score for each child one mark

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[1] The Test was constructed by a Committee of the Research Grant Board of the Government of the Union of South Africa. The Board financed the work of the Committee and the research of which the present paper is an account. The members of the committee were: Professor R. W. Wilcocks (Chairman), Professor R. F. A. Hoernlé, Professor J. Chr. Coetzee, Professor H. A. Reyburn, Professor J. J. Strasheim, Mr. P. J. Oosthuisen, Dr. L. van Schalkwyk, Dr. J. T. Dunston, Dr. M. L. Fick, Dr. H. E. Brown, Mr. O. K. Winterton, and Mr. I. D. MacCrone.

[2] Constructed on lines similar to the test of this name in Otis' Advanced Scale.

[3] Constructed on lines similar to the test of this name in Otis' Advanced Scale.

[4] This made it possible to employ a number of testers. The test results on which the present paper is based were obtained by the following, who either applied the Test or instructed testers, many of whom were teachers, in the use of the Test and organized the application in different groups of schools: Professor R. F. A. Hoernlé, Professor J. J. Strasheim, Mr. P. J. Oosthuisen, Professor J. Chr. Coetzee, Dr. E. G. Malherbe, and Professor H. A. Reyburn. About one half of the results were obtained by the author or by testers instructed by him.

is given, first of all, for each item answered correctly, except in the case of same-opposites, where this first score is given on right-wrong answers. The scores on each test obtained in this way are then weighted, so as to make the standard distributions of the tests approximately equal, and then totalled. These we shall call original weighted scores in order to distinguish them from standard totals, to be discussed in the sequence, which were scaled so as to rise with equal steps of difficulty. Table 1 gives the data with regard to the standard deviations of each test on one of the forms of the battery. It may, however, be added that the correlation, by the Bravais-Pearson formula, for 300 children, of the age of 14 years at the last birthday, between weighted and unweighted totals of original scores is .970, *P.E.*=.002. The coefficient of reliability of the battery is r=.93, *P.E.*=.03, as obtained by means of the application of

TABLE 1

STANDARD DEVIATIONS FOR UNWEIGHTED SCORES ON EACH TEST OF THE SOUTH AFRICAN GROUP TEST OF INTELLIGENCE

Columns III to IX give the standard deviations in unweighted scores. In the first column are given the numbers of children on whose performances the standard deviations were worked out. The second column gives the ages of the groups. The last row gives, firstly, the averages of the standard deviations, equal weight being given to each standard deviation. The numbers between parentheses are the divisors by which the score on each test is weighted. The weighted total on all the tests is rounded off to the nearest whole number in practice.

I	II	III	IV	V	VI	VII	VIII	IX
No. indivs.	Age in months	Test 1	Test 2	Test 3	Test 4	Test 5	Test 6	Test 7
120	120-131	2.93	5.31	3.36	5.56	3.12	8.40	2.82
127	132-143	2.92	3.72	3.63	6.50	2.56	9.27	2.96
145	144-155	3.25	5.90	4.57	7.16	3.42	9.37	2.60
151	156-167	3.06	6.61	4.82	7.29	3.92	11.04	3.99
182	168-179	4.23	7.14	4.92	7.02	3.60	10.93	4.13
168	180-192	3.07	8.75	4.60	6.52	3.40	9.47	4.22
Average $\sigma_{dis.}$		3.24	6.24	4.32	6.68	3.17	9.75	3.45
		(1)	(2)	(1)	(2)	(1)	(3)	(1)

TABLE 2

PERCENTAGES OF CHILDREN OBTAINING NO MARKS AND MAXIMUM MARKS ON THE INDIVIDUAL TESTS OF THE BATTERY

The left-hand sides of Columns III to IX show the percentages of children obtaining no marks at all on the component tests, the right-hand sides of the columns showing the percentages of children obtaining maximum marks. The first column shows the number of children on whose performances the results were calculated, the second column giving the ages in months.

I	II	III		IV		V		VI		VII		VIII		IX	
No. indivs.	Age in months	Test 1		Test 2		Test 3		Test 4		Test 5		Test 6		Test 7	
		0	max.	0	max.	0	max.	0	max.	0	max.	0	max.	0	max.
120	120-131	3.3	0	5.0	0	24.2	0	10.0	0	8.3	0	16.7	0	7.5	0
127	132-143	1.6	0	1.6	0	23.6	0	5.5	0	.8	0	10.2	0	5.5	0
145	144-155	2.1	0	2.1	0	13.8	.6	4.8	0	3.4	0	10.4	0	2.1	0
151	156-167	.6	0	.6	.6	9.3	0	2.0	0	4.6	0	6.0	.6	1.3	0
182	168-179	1.7	0	.6	.6	7.1	0	1.7	0	1.7	0	6.5	3.8	1.7	0
168	180-192	.6	0	1.2	0	3.0	0	.6	0	.6	0	3.6	2.4	1.8	0

equivalent forms of the battery to 191 children of both sexes of 120 to 192 months old, standard scores being used. Fourteen days elapsed between the two applications. The standard errors of estimate ($\sigma_1.\infty = \sigma_1\sqrt{1-r_{11}}$ and $\sigma_2.\infty = \sigma_2\sqrt{r_{11}}$) were 3.19 and 3.11 with a mean of 3.15 standard points. The correlation between age and score in standard points at first application of the battery to a child was $r = .575$, $P.E. = .03$. Of the 16,574 children tested, all being of European descent, on whose performances we are reporting here, few were unable to obtain any marks at all on the whole battery, and none obtained the maximum number of marks possible. In the main, it appears that only small percentages of the children are unable to obtain any marks on constituent tests of the battery, but in the case of some of these tests the percentages are rather large. Details on these points are given in Table 2 for one of the forms of the battery. Inspection of the table shows that the constituent tests largely cover the same range of difficulty. Since they do not, however, quite do so, the question is raised as to the extent to which scores on only a portion of the tests may be used to take the place of scores on the whole battery. Light is thrown on this question by the information given in Table 3, which contains the inter-correlations between the constituent tests. The inter-correlations are based on the results obtained from 200 children of the ages 144 to 150 months, standard scores being used. The children form a random selection with the exception that no child was included who scored no marks on one or more of the constituent tests, this being done on account of the indefiniteness of the meaning of "no marks." It is clear that "no marks" does not show how far the child in question fell short in the ability to score at least one point. The tetrad differences between these correlations were calculated. The

TABLE 3

INTERCORRELATIONS BETWEEN THE CONSTITUENT TESTS

	Test 6	Test 4	Test 7	Test 3	Test 1	Test 5	Test 2
Test 6		.5286	.4822	.5355	.5076	.5107	.4358
Test 4	.5286		.4858	.4866	.5441	.4381	.4738
Test 7	.4822	.4858		.5259	.4262	.4646	.4596
Test 3	.5355	.4866	.5259		.4247	.3934	.4085
Test 1	.5076	.5441	.4262	.4247		.3754	.3645
Test 5	.5107	.4381	.4646	.3934	.3754		.3450
Test 2	.4358	.4738	.4596	.4085	.3645	.3450	

TABLE 4

CORRELATION OF EACH CONSTITUENT TEST WITH "*g*"

Test	6	4	7	3	1	5	2
Correlation with "*g*"	.75	.74	.705	.68	.64	.61	.60

distribution of tetrad differences showed a median deviation of .0223. The *P.E.* of the distribution was .0239,[5] so that median and *P.E.* are in close agreement. On Spearman's theory of two factors, we may thus look on the correlations as resulting from a general factor ("*g*") and a number of specific factors. If equal weight be given to each test, the correlation, calculated from the information in Table 3,[6] between standard scores on the whole battery and "*g*" is $r=.92$ (uncorrected for attenuation). The battery as a whole may thus be looked on as a good test of "*g*." The correlations between each of the constituent tests and "*g*" are given in Table 4. From Table 4 we are able to calculate[7] that, if we omit Tests 3, 4, 5, and 6, where the largest percentages occur of children obtaining no marks, then the remaining tests still correlate with "*g*" to the extent of $r=.81$ (uncorrected for attenuation). Cases where a child obtains no marks on these four, or any other four, of the tests, occur only rarely in practice. It is clear, however, that even then the remaining tests appear to test, quite in the main, what is tested by the whole battery.

THE COMPARISON OF THE FOUR FORMS OF THE SOUTH AFRICAN GROUP TEST OF INTELLIGENCE

We have stated that use was made of four forms, i.e., batteries, of the South African Group Test. Some children were tested with one form and some with another. In view of the question of the comparability of the results, we wish, now, to turn to the consideration of the equivalence of the four forms with regard to nature and difficulty. Two of the forms (A1 and A2) are in Afrikaans, the language spoken by a part of the European population of South Africa. The other two forms (E1 and E2) are in English, the language spoken by another part. In constructing the four forms of the battery we were guided by the aim, *inter alia,* of making the four forms as nearly as practically possible of equivalent nature and difficulty. In the trial forms, drawn up at the beginning of the test construction, each sub-test contained a much larger number of items than were selected for use in the final forms of the battery. In the original trial forms the items were arranged roughly in order of difficulty according to subjective estimate and these trial forms were applied to some 500 children, a child being given as much time as he could usefully dispose of in attempting to do the test items. On the basis of the results so obtained several kinds of tests, which appeared to be less suitable for one or another reason, were eliminated, and a number of minor changes were made in the tests which were retained. The full selected and amended tests were then applied to some 1500 children, the same principle as that described above being followed with regard to time limits. The percentage of correct answers on each test item was then determined on the new results, and the items were scaled in order of difficulty on the basis of these percentages. In doing so, use was made of the Kelley-Wood Tables[8] to obtain the sigma value for the percentage of correct answers to each item. Forms A1 and A2 of the battery were obtained by now selecting from the trial items for each test pairs of items which corresponded as nearly as possible in sigma value. One of such a pair of items was allocated to Form A1 and the other to Form A2. The easiest item among those selected for a test in a form was then placed first on the list, and the most difficult last, the intermediate items being so chosen, in addition, that the sigma differences remained approximately constant from one item to the next, the order being that of rising difficulty. Exactly the same procedure was followed in the case of the Forms E1 and E2. It could, thus, reasonably be expected that A1 and A2 would be practically equal in nature and difficulty with each other, and that this would also be the case as between E1 and E2. However, a verification of this expectation was carried out. This was done on the results obtained from the application of the four forms of the battery in their final shape. Table 5 gives the data for A1 and A2. It is evident from the table that only small differences occur between the averages (in weighted original points) of the pairs of groups doing A1 or A2, but of the same age and school standard, and the sum of the differences divided by 7 (the number of pairs) is only .5 of a point, so

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[5] See Spearman [4, Appendix II, 3, Equation 16 (A)].
[6] See Spearman (Appendix IV, 2, Equation 21).
[7] See footnote 6.

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[8] See Kelley (1, Appendix C).

TABLE 5

Weighted Original Scores on Forms A1 and A2

In the first column is given the age at last birthday; in the second column, the standard in school of the children; in the third, the number of children obtaining as their average the score given in the fifth column. The fourth column gives the form of the battery used and the sixth gives the differences between the averages, the difference being marked + if the score on A1 is higher than on A2, and being marked — if the opposite is the case.

Age last birthday	School standard	Number of indivs.	Form of test	Average score	Difference
10	II	154	A1	20.2	—.2
10	II	195	A2	20.4	
11	IV	176	A1	44.1	+.2
11	IV	186	A2	44.3	
13	V	176	A1	52.0	+.5
13	V	128	A2	51.5	
14	VI	188	A1	60.2	—.2
14	VI	182	A2	60.4	
15	VII	224	A1	67.4	+.8
15	VII	103	A2	66.6	
12	VI	65	A1	70.3	+.6
12	VI	68	A2	69.7	
15	VIII	150	A1	81.9	+1.9
15	VIII	121	A2	80.0	

Number of individuals (A1) = 1133
Number of individuals (A2) = 983
Av. diff. = .5

that A1 and A2 are evidently of practically equal difficulty. The individual scores cover the whole range from highest to lowest scores. The data for E1 and E2 are given in Table 6. As in the case of Table 5 the differences between the averages of the pairs of the same age and school standard doing different forms of the battery are nowhere large and again vary in a chance manner. The average difference is approximately .7 of a point, so that E1 and E2 are also to be looked upon as being of practically identical difficulty. As in the case of Table 5, the individual scores cover the whole range from the highest to the lowest scores.

The next question has reference to the relation of nature and difficulty between the A- and E-forms of the battery. Some of the tests were originally drawn up in Afrikaans, and others were originally drawn up in English. The items were then translated into either English or Afrikaans in such a way that, as far as could be judged subjectively, the original and the translation were as nearly as possible of equal difficulty. It appeared, however, on arranging the

TABLE 6

WEIGHTED ORIGINAL SCORES ON FORMS E1 AND E2

In the first column is given age at last birthday; in the second, the standard in school of the children; in the third the number of children obtaining as their average the score given in the fifth column. The fourth column gives the form of the battery used and the sixth the differences between the averages, the difference being marked + if the score on E1 is higher than on E2, and being marked — if the opposite is the case.

Age last birthday	School standard	Number of indivs.	Form of test	Average score	Difference
10	III	61	E1	34.8	+1.7
10	III	30	E2	33.1	
11	IV	44	E1	42.6	—3.4
11	IV	39	E2	46.0	
13	V	36	E1	53.2	+4.5
13	V	30	E2	48.7	
12	V	59	E1	59.0	+ .8
12	V	49	E2	58.2	
14	VI	33	E1	60.3	+ .2
14	VI	27	E2	60.1	
11	V	36	E1	64.4	—4.0
11	V	31	E2	68.4	
13	VI	47	E1	68.3	—2.7
13	VI	28	E2	71.0	
12	VI	28	E1	71.0	+2.4
12	VI	33	E2	68.6	
15	VII	25	E1	70.0	—2.1
15	VII	20	E2	72.1	
13	VII	28	E1	82.2	— .8
13	VII	35	E2	83.0	

Number of individuals (E1) = 397
Number of individuals (E2) = 322
Av. diff. = .7

items in order of difficulty on the basis of trial test results in the way previously described, that items which corresponded to each other as original and translation sometimes did not show correspondence when arranged in order of difficulty according to test results. The selection of items for the A- and E-forms of the battery was, therefore, carried out in independence of one another, but according to the method which has already been described. An objective comparison of the A- with the E-forms could, however, still be carried out on the basis of test results. This was made possible by the fact that the language difficulty does not occur with regard to one kind of test, namely, number completion. The items of this test in A1 are exactly the same in E1, the items in A2 and E2 also agreeing exactly with each other. Directions were always given in the language with which the child was most familiar, and in this respect practical equivalence was not difficult of attainment. For 200 children taking the test in Afrikaans, of the ages 144 to 150 months, who had obtained scores of from 1 to 18 points on the number completion test, the correlation was worked out between their performances on the number completion test and their total performance on the rest of the tests, scores on tests being weighted, before adding, in the method previously described. The correlation was $r = .560$, $P.E. = .035$. The correlation was also worked out for a group of 200 children taking the test in English, but similar to the Afrikaans group with regard to distribution of age and marks in the number completion test. In this case $r = .542$, $P.E. = .035$. The *P.E.* of the difference between the two coefficients was calculated by the formula $P.E. = \sqrt{(P.E._A)^2 + (P.E._E)^2}$ and gives a value of .049, which is considerably larger than the difference of .018 between the coefficients, so that this difference must be looked upon as statistically quite insignificant. It thus appears that the relation between degree of ability to do the number completion test and the ability to do the rest of the tests as a whole is practically identical for the Afrikaans-speaking children, doing an A-form, and the English-speaking children doing an E-form of the battery. Notwithstanding this agreement, it might still be possible for total A-scores on the tests other than number completion to be higher or lower than the corresponding E-scores, even where the scores on number completion were the same in the two cases. To settle this question we may take the results of two groups of children, one group having been examined by an A-form of the battery and the other by an E-form, selecting the children so that each child of both groups has the same score on the number completion test and making our two groups homogeneous also in other respects, namely, age and school standard, which may be expected to affect performance on the rest of the tests of the battery. We may then expect that any difference of difficulty between the A- and E-forms must come to light when we compare the scores of the two groups on the rest of the tests. Absence of any significant difference would enable us to conclude that the A- and E-forms were equally difficult. A comparison was carried out on this principle, the data for a number of such paired groups being given in Table 7, A2 and E2 being the forms of the battery used. For the children whose results are tabulated, individual scores again

TABLE 7

EQUIVALENCE OF AN A-FORM AND AN E-FORM OF THE BATTERY

In the first column we have the ages at last birthday of the groups compared, in the second column the school standard of each member of a group. The third column gives the score obtained by each member of a group on the number completion test. The two portions of the fourth column gives the number of children who did the A- or the E-form, and the two portions of the fifth column contain the average total scores obtained by these children on the tests other than number completion. In the last column on the right this average score, for the E-children, is shown as a percentage of the average score of the A-children.

Age last birthday in years	School standard	Score in Number Test	Number indivs.		Av. total on rest of tests		Eng. total as percentage of Afr.
			Afr.	Eng.	Afr.	Eng.	
10	III	1	34	48	23.0	25.5	110.9
		2	18	33	31.0	27.4	88.4
		3	15	20	30.8	32.8	106.5
		4	15	20	31.1	31.6	101.6
		5	16	26	35.8	39.3	109.8
		6	17	21	39.1	38.0	97.5
11	IV	1	13	23	31.6	30.8	97.5
		2	21	26	35.8	37.0	103.4
		3	20	23	37.5	35.6	94.9
		4	31	21	38.0	39.1	102.9
		5	10	12	45.5	45.0	98.9
		6	9	25	45.6	43.8	96.1
		7	10	24	48.0	46.5	96.9
12	IV	1	14	18	26.0	34.3	130.8
		2	12	15	31.0	30.4	98.1
		3	11	12	34.6	37.8	109.3
		4	12	16	37.8	36.0	95.3
		5	18	15	38.3	43.9	114.6
		6	10	8	40.6	47.6	117.2
		7	12	8	44.6	46.7	104.7
		8	7	3	54.3	48.7	89.7
		9	7	8	43.3	52.5	121.3
		10	3	7	64.0	48.7	76.2
		11	6	5	47.7	52.8	110.7
13	V	2	4	5	45.5	47.2	103.7
		3	5	2	49.4	46.0	93.2
		4	3	8	59.3	53.6	90.4
		5	5	7	67.5	62.1	92.0
		6	5	10	64.2	57.2	89.1
		7	7	14	61.7	57.0	92.4
		8	16	15	60.6	66.5	109.7
		9	13	18	67.3	62.5	92.9
		10	14	17	66.6	63.8	95.8
		11	11	37	72.3	65.8	90.0
		12	9	15	71.7	74.4	103.8
		13	13	18	74.0	75.7	102.3
		14	5	18	75.6	79.3	104.9

TABLE 7 (*continued*)

14	VI	4	17	12	46.9	51.3	109.4
		5	10	7	53.6	58.2	108.6
		6	13	9	58.3	52.7	90.4
		7	10	7	59.0	60.1	101.9
		8	16	20	59.0	57.95	98.2
		9	16	18	60.1	60.7	101.0
		10	17	18	63.4	62.4	98.4
		11	12	26	71.6	69.2	96.6
		12	18	10	67.0	71.6	106.9
		13	8	13	69.5	72.8	104.7
		14	7	13	81.4	78.0	95.8
		15	5	9	76.8	80.2	104.4
14	VII	8	14	10	66.6	64.9	97.4
		9	17	11	68.2	70.0	102.7
		10	14	21	73.6	72.6	98.6
		11	23	23	72.9	78.8	108.1
		12	19	20	75.2	80.7	107.3
		13	21	23	80.0	84.2	105.2
		14	10	23	78.8	85.0	109.0
		15	14	25	82.6	85.4	103.4
		16	11	16	86.4	88.6	102.5
		17	9	16	88.6	92.1	103.9
		18	11	12	89.5	89.9	100.3
15	VII	8	13	9	69.0	67.4	97.7
		9	23	4	68.4	65.7	96.1
		10	25	10	70.9	68.3	96.4
		11	16	9	78.3	80.8	103.2
		12	19	13	72.7	76.2	104.8
		13	16	11	77.7	78.2	100.6
		14	11	15	70.7	78.0	110.3
		15	14	11	84.5	79.6	94.2
		16	11	9	86.7	93.0	107.3

Totals: 911 A-children and 1074 E-children. Av. diff. = 1.7%

covered the range of totals from practically the lowest obtained to the highest obtained by our total group of 16,574 tested, both with regard to number completion and the totals on the rest of the tests. Inspection of the last column of the table shows that the relation between the A- and E-totals varies in an irregular way, the A-total on the remaining tests being the bigger in some cases and the E-total in others. The average difference on the data of column six is 1.7%. In addition .675 σ of the E-scores, expressed as percentages of the A-scores, is 5.1, which is much larger than the average difference between A- and E-scores expressed as percentages. The minute average difference between A- and E-scores is, thus, statistically insignificant, so that we are justified in treating the A- and E-forms

TABLE 8

Distribution According to Age of the Total Number of Children Tested

Total tested = 16,574

Age groups (months)	Number tested	Age groups (months)	Number tested
120-131	2375	156-167	3015
132-143	2546	168-179	3255
144-155	2763	180-192	2620

of the battery as of equal difficulty. The results obtained by means of Forms A1, A2, E1, and E2 can thus be viewed as obtained by equivalent forms and are thus treated in the sequence.

The Steps Taken to Make the Results Representative of the School-going Child of European Descent in the Union of South Africa

In order to have representative data for determining the distribution and growth of intelligence for an area or country, the question of selection, naturally, becomes of great importance. To this question we now have to turn. Our calculations for the distribution and growth of intelligence are based on the test results obtained with 16,574 school-going children of European desent in the Union of South Africa. Afrikaans- and English-speaking children were represented in this total in practically equal numbers, this also being true with regard to relation of the number of boys to girls. Almost 45% of the children were from urban areas, the rest coming from small townships, villages, and farms from almost all parts of the Union. The distribution of the children, according to age, is given in Table 8. The lowest age of a child included in the table was 120 months, and the results are not included of children who had actually reached their sixteenth birthday.

Very complete data collected for the Union by the Departments of Education of the different Provinces and assembled by the Census Department of the Union Government enabled us to treat our data in a way which considerably enhanced the representative nature of our conclusions. Testing was carried out mainly during 1929, and the Union Yearbook of the Census Department for 1928-1929 gives the distribution of European school-going children in the Union,[9] during 1928, according to age and school standard attained. In all,

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[9] (7, p. 158).

TABLE 9

Distribution of Children by Age and Standard for the Whole Union of South Africa and of Those Tested

Age last birthday	Below Std. I	Std. I	Std. II	Std. III	Std. IV	Std. V	Std. VI	Std. VII	Std. VIII	Std. IX	Std. X	Total
9	22.630	36.976	29.806	9.568	.976	.038	.006					100%
10	6.939	20.924	34.742	27.982	8.440	.922	.048	.003				100%
	2.670	8.719	27.242	38.256	19.316	3.338	.459					100%
11	2.086	7.979	22.730	33.482	24.942	7.790	.942	.046		.003		100%
	.788	3.387	11.855	25.798	36.658	18.039	3.309	.166				100%
12	.890	3.216	10.262	23.946	31.500	22.877	6.570	.693	.046			100%
	.143	1.048	5.315	14.931	25.597	28.814	20.933	3.073	.146			100%
13	.385	1.310	4.544	13.017	24.259	30.015	21.022	4.798	.630	.017	.003	100%
	.032	.729	1.756	6.196	13.983	25.050	32.240	17.727	2.121	.166		100%
14	.217	.578	2.057	6.478	15.562	26.252	30.794	13.762	3.857	.422	.021	100%
	.030	.184	.738	2.643	7.130	16.135	27.597	31.500	12.415	1.628		100%
15	.135	.278	1.076	3.713	9.008	19.265	30.683	20.322	11.910	3.224	.386	100%
	.076	.098	.229	1.296	3.751	10.023	17.912	28.811	25.838	10.861	1.105	100%
16	.396	.096	.389	1.407	3.736	9.945	23.830	22.061	22.192	12.178	3.770	100%

there were 198,263 such children, from 10 to 15 years old at last birthday, in attendance. In Table 9 we give the Census figures, but expressed, for purposes of convenience of comparison, as percentages. These are given in the first line of the rows, the second line of the rows giving the percentages for the children tested. The first and last rows contain only Census percentages. A comparison shows that there are often considerable differences between the two sets of percentages in the same compartments of the table. There is a clear tendency for the children tested at each age to be in higher standards at school, on the average, than for the Union as a whole. We may now look on the tested children of each age and standard as representative of all European children in the Union of the same age and standard. Thus, tested children of, say, ten years old and in Standard I at school are looked on as representative of all children of ten years old and in Standard I in the Union, and so on for other age-standard groups. We expect, in other words, that the results we obtain by testing a number of European children of a particular age-standard group will give us a true picture of what would be the performance of all the Union's European children of that age-standard group. We, therefore, have to attach weights to the scores of the children tested, the weights being, for each age-standard group of tested children, the Census percentages for the same age-standard group.

The Census figures are, however, limited to year groups, and for our purpose it was desirable to have a finer differentiation according to age, namely, into month groups, since we wished to trace the growth of intelligence from month to month. Failing to have the actual figures for this finer differentiation, we proceeded to calculate them on the assumption that a sufficiently close approximation to the actual numbers could be obtained by linear interpolation. That is, we assumed that the relation of the proportion of children of just 9½ years old in Standard I to the proportion of children of just 10½ years old in Standard I would be the same as the relation of the proportion of all 9-year-old school-going children, at last birthday, to the proportion of all 10-year-old school-going children at last birthday. A similar assumption, with the obvious modifications necessary, is made with regard to the relation of the proportion of children just 10½ years old in Standard I to the proportion of those just 11½ years old in Standard I. Once having got figures for the children in Standard I just 9½ years old and for those just 10½

TABLE 10

Illustration of the Method of Weighting in Order to Make Our Data Representative

(Children of 120 months to the nearest month.)

The first column gives scores in original weighted totals. The next six columns give the actual numbers of 120-month-old children tested and found in each of the grades or standards listed at the top of the columns and having the scores given in the first column. The next to the last column gives the total number of 120-month-old children testing at the scores given in the first column, the last entry giving the total number of children tested at this age. The entries at the bottoms of each column from the second to the seventh, inclusive, give the weights calculated by interpolation from the Census figures. The number of individuals listed in these columns is multiplied by the weight. The last column on the right gives the weighted number of individuals getting a certain score, the entry at the bottom of the column giving the total weighted number of individuals of the age of 120 months. The entries in the last column are used for working out medians, averages, standard distributions, etc., for the weighted number of individuals.

Score in orig. pts., weighted	Number of children tested							
	below Std. I	in Std. I	in Std. II	in Std. III	in Std. IV	in Std. V	Total tested	Weighted total
0	2						2	29.6
1-4	5	9	2				16	399.0
5-8	2	7	7				16	458.1
9-12	2	9	4				15	419.2
13-16	2	6	14	5			27	749.0
17-20		2	12	6			20	557.8
21-24		1	7	5			13	348.7
25-28			7	7	1		15	362.1
29-32		1	4	5	3		13	266.0
33-36		1	1	5	2		9	164.5
37-40			5	8			13	311.6
41-44			2	5	1		8	163.1
45-48				1	1		2	23.5
49-52				1	2		3	218.2
53-56				1		1	2	19.3
57-60				1		1	2	19.3
61-64				1			1	18.8
65-68						1	1	.5
69-72								
73-76								
77-80					1	1	2	4.7
Weights	14.8	29.0	32.3	18.8	4.7	.5	180	4343.0

years old, the figures for the intermediate ages could be obtained by linear interpolation. So, too, the figures for the ages, intermediate between 10½ and 11½, of children in Standard I, could be obtained by this method of calculation. This principle was followed right through in order to get the percentages of children of all grades and

TABLE 11

Weighted Distributions for the Six Broad Age Groups

The first column gives scores in terms of original weighted totals from 0 to the maximum of 121 possible on the battery. The next columns give the weighted numbers of individuals, for each of the six broad age groups, who reach the scores given in the first column. The weighted numbers of individuals were obtained by adding together weighted totals such as those given in the last column of Table 10.

Score in orig. pts. weighted	Weighted totals of children tested in the age groups (in months):					
	120-131	132-143	144-155	156-167	168-179	180-192
0	142.2	27.3				17.6
1-4	1462.4	291.6	112.7	25.6	23.1	12.5
5-8	2762.0	801.0	408.9	110.3	64.4	13.3
9-12	3372.8	1705.2	669.5	289.6	160.1	107.0
13-16	5980.2	2688.1	1344.3	546.7	216.9	65.2
17-20	5668.9	3602.1	2403.7	753.0	467.6	194.2
21-24	6956.8	4597.2	2633.4	1399.4	827.6	313.1
25-28	6230.4	5092.0	2931.5	2153.1	1353.8	509.4
29-32	5814.5	5323.2	4332.9	2672.3	1730.3	727.8
33-36	4106.7	4877.1	4683.7	3346.7	2086.1	978.9
37-40	3930.7	5433.7	4732.2	3341.2	2639.0	1455.4
41-44	2797.1	4484.4	4742.8	3824.0	3390.1	2043.0
45-48	2078.0	3964.5	4419.4	3556.3	3434.5	1990.2
49-52	1767.2	2868.9	3818.0	4045.9	4275.0	2424.4
53-56	1166.2	2795.2	3456.3	4124.4	5799.9	3327.3
57-60	709.9	1763.5	3235.3	4674.7	4342.1	3151.8
61-64	362.9	1569.1	2490.5	4139.0	4309.7	3217.6
65-68	360.1	1075.2	3065.4	3688.9	4823.6	2771.1
69-72	315.4	651.1	1892.5	3275.6	4079.4	3215.4
73-76	216.6	678.2	1428.2	3582.0	3614.6	3339.8
77-80	132.9	423.8	1237.4	2292.2	3203.2	2823.2
81-84	22.4	142.5	715.4	1575.9	3001.7	2863.8
85-88	13.6	193.1	618.8	1289.4	2158.5	2554.9
89-92	12.9	71.9	411.6	1161.3	1988.0	2087.1
93-96		21.8	333.1	719.1	1043.7	1731.3
97-100	1.5	23.8	147.9	468.3	754.9	1070.7
101-104		5.2	56.7	197.5	601.8	754.4
105-108			43.5	75.4	141.1	323.3
109-112	.3	3.3	2.1	41.4	140.0	92.3
113-116				2.7	29.4	47.5
117-120					1.4	9.2
121						

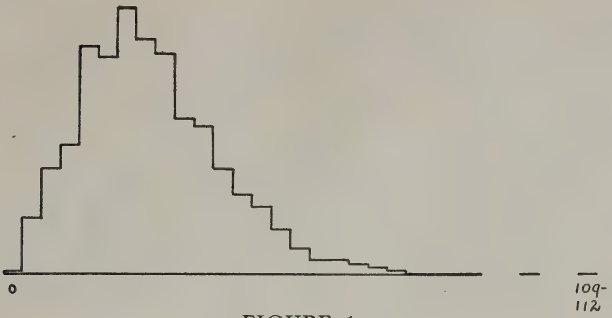

FIGURE 1
Weighted Distribution of the Age Group of 120-131 Months with Successive Weighted Original Scores Taken at Equal Distances on the Abscissa

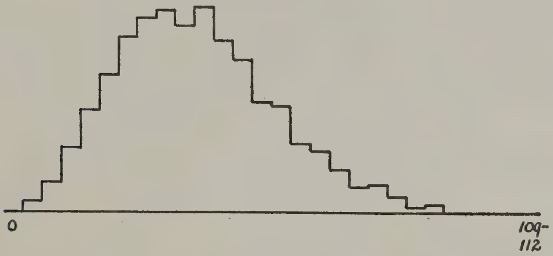

FIGURE 2
Weighted Distribution of the Age Group of 132-143 Months with Successive Weighted Original Scores Taken at Equal Distances on the Abscissa

standards from the ages of 120 to 192 months. The weights calculated in this way were then used in the manner illustrated in Table 10, which is one of the 73 distributions made for the month groups from 120 to 192 months. These data are too voluminous for full publication.

The Construction of a Scale of Total Scores with Steps of Equal Difficulty, and the Normality of the Distribution of Intelligence

In Table 11 we give the distributions, weighted[10] in the way just described, for the age groups (in months): 120-131, 132-143, 144-155, 156-167, 168-179, and 180-192. In Figures 1 to 6 the distri-

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[10] See Table 17 for the unweighted distributions.

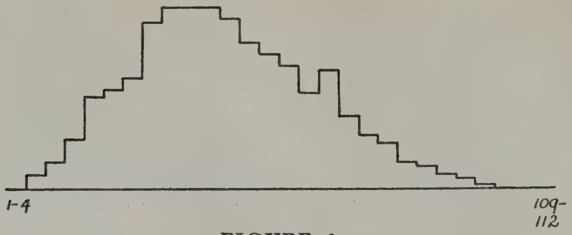

FIGURE 3

Weighted Distribution of the Age Group of 144-155 Months with Successive Weighted Original Scores Taken at Equal Distances on the Abscissa

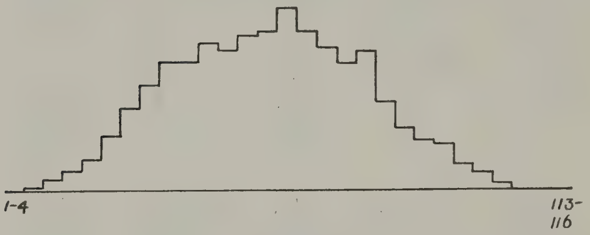

FIGURE 4

Weighted Distribution of the Age Group of 156-167 Months with Successive Weighted Original Scores Taken at Equal Distances on the Abscissa

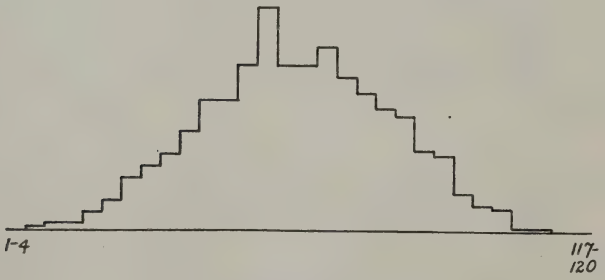

FIGURE 5

Weighted Distribution of the Age Group of 168-179 Months with Successive Weighted Original Scores Taken at Equal Distances on the Abscissa

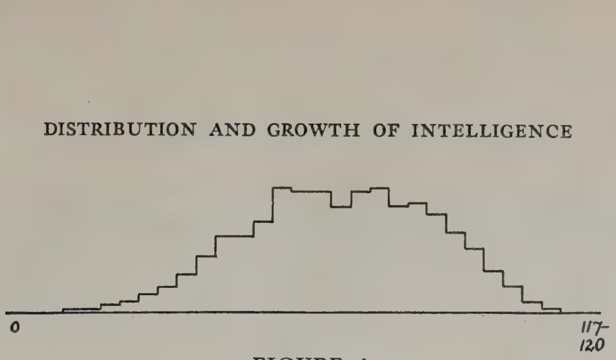

FIGURE 6
WEIGHTED DISTRIBUTION OF THE AGE GROUP OF 180-192 MONTHS WITH SUCCESSIVE WEIGHTED ORIGINAL SCORES TAKEN AT EQUAL DISTANCES ON THE ABSCISSA

butions are represented graphically, original weighted scores being given on the *x*-ordinate and the weighted number of individuals on the *y*-ordinate. The curves in Figures 1, 2, and 3 are skewed to the right, but the tendency decreases with the growth of age. In the case of Figure 6, the curve is skewed to the left, but this tendency decreases in the case of Figures 5 and 4, i.e., with decrease of age. One hypothesis with regard to these curves would be that the totals in terms of original weighted scores form a series of steps of equal difficulty, and that, on such a scale, our six broad age groups form different a-normal distributions of the kinds the curves show. Another hypothesis is that these totals do not form a series of steps of equal difficulty, but that there are inequalities in the steps of the series of totals and that the distributions would be normal should these inequalities be removed. So, e.g., in the case of the group 120-131, the skewness would then be due to the fact that it is comparatively difficult in the case of a low total to rise to the next higher total, so that the individuals tend to pile up over this part of the abscissa. After proceeding some distance to the right, we reach totals where the differences in difficulty between successive totals decrease, with the result that children reaching this region differentiate more easily in score and that changes in the height of the curve become more gradual. In the case of the age group 132-143 the same hypothesis would hold true in principle. Only, in this case, the children test somewhat higher on the whole because of their greater age, and the number of those becomes smaller who are unable to pass the initial region of relatively large differences of difficulty. At the other extreme we have the age group 180-192, where the curve tends to drop more suddenly on the right, i.e., the individuals tend to pile up in the region of very high totals. On the hypothesis, this would have to be explained as being due in this region to increased degrees of differences of difficulty between successive totals. On the other hand, the differences in difficulty would decrease as we leave the region of the highest scores and proceed to the left, i.e., to the medium scores and the upper portion of the lower scores of this age group, with the resulting increase of differentiation. On this hypothesis we would also expect the curves for intermediate age groups to show a tendency towards becoming platykurtic. This appears, also, to be the case, as can be seen clearly in the case of the age group of 157-167 months. The highest age group (180-192 months) also clearly shows this tendency. On the hypothesis, this would be explicable as being due to many of the children of this group obtaining totals falling in the intermediate region of greater differentiation.

We proceeded to test this hypothesis, making use in principle of a method of scaling given by Thorndike.[11] So, e.g., on the assumption that the age group 120-131 would form a normal distribution with the South African Group Test if successive totals were separated by equal degress of difficulty, the degree of difficulty attaching to a total can be measured in terms of distances along the abscissa, equal sigma differences standing for equal differences of difficulty. We, therefore, transformed each of the six distributions into normal distribution. In doing so we made use of the Kelley-Wood[12] and Sheppard Tables[13] of the normal curve, by which it is possible to determine the sigma value of each original weighted total score from the percentage of children obtaining the score in question. This procedure we carried out for each of our six broad age groups. Should it, now, appear that the six independent determinations of the sigma differences of successive original weighted totals give us the same, or nearly the same values, then the second hypothesis mentioned above may be looked on as proved, namely, that the distributions in Figures 1 to 6 are really due to inequalities of steps of difficulty between successive original weighted totals, and that the "true" distributions would be normal.

Table 12 gives the results of treating each of the six weighted distributions independently in the way just described. The sigma values of different original weighted totals are, however, not yet in comparable form, since we have as yet not expressed them in a com-

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[11] See Thorndike (5, Chap. VII).
[12] See footnote 8.
[13] See Pearson (2, Table II).

TABLE 12

SIX INDEPENDENT DETERMINATIONS OF THE SIGMA VALUES OF ORIGINAL WEIGHTED SCORES BEFORE REDUCTION TO A COMMON UNIT AND A COMMON POINT OF MEASUREMENT

In the first column we have totals (from the lower to the upper limits of the class intervals) in terms of original weighted scores. In the next six columns are given the sigma values of the upper limits for each of the six age groups.

Score in orig. pts. weighted	Values in terms of the sigmas of each of the age groups (in months):					
	120-131	132-143	144-155	156-167	168-179	180-192
0	–2.747781	–3.293610				–3.341824
1-4	–1.895698	–2.512144	–2.878161	–3.322450	–3.369568	–3.195284
5-8	–1.446632	–2.014091	–2.365619	–2.824390	–2.976728	–3.099518
9-12	–1.093897	–1.635234	–2.014091	–2.457264	–2.575829	–2.705253
13-16	–.696685	–1.281552	–1.684941	–2.120072	–2.408916	–2.583390
17-20	–.401571	–.974114	–1.346939	–1.880794	–2.144411	–2.354580
21-24	–.082813	–.677640	–1.093897	–1.607248	–1.895698	–2.130540
25-28	.196780	–.409735	–.877896	–1.328539	–1.625763	–1.911036
29-32	.467699	–.158580	–.618873	–1.084823	–1.398377	–1.706044
33-36	.683961	.065219	–.379927	–.852386	–1.200359	–1.506262
37-40	.926859	.316003	–.156042	–.658838	–.998576	–1.287271
41-44	1.140688	.538836	.060195	–.462113	–.785774	–1.053744
45-48	1.340755	.762101	.261120	–.297611	–.603765	–.874217
49-52	1.563224	.950221	.448212	–.115562	–.401571	–.690309
53-56	1.762410	1.174987	.628006	.065219	–.176374	–.464904
57-60	1.943134	1.353174	.816875	.274110	.007520	–.274110
61-64	2.074855	1.554774	.986271	.467699	.186576	–.087845
65-68	2.226211	1.750686	1.155221	.655727	.398855	.067731
69-72	2.457264	1.911036	1.340755	.845199	.588793	.253347
73-76	2.747781	2.144411	1.522036	1.098468	.782365	.453762
77-80	3.121689	2.408916	1.727934	1.304685	.978150	.640265
81-84	3.280535	2.512144	1.895698	1.483280	1.210727	.855996
85-88	3.469495	2.878161	2.096927	1.684941	1.418654	1.089349
89-92	3.999571	3.090229	2.290370	1.943134	1.695398	1.334622
93-96		3.244080	2.575829	2.197286	1.911036	1.625763
97-100	4.416666	3.608330	2.878161	2.512144	2.170090	1.911036
101-104		3.846540	3.147395	2.878161	2.575829	2.301680
105-108			3.956667	3.167528	2.747781	2.705915
109-112				3.905263	3.280481	3.015778
113-116					4.072000	3.529741
117-120						
121						

mon unit of measurement and from a common starting-point. In order to carry out this reduction of measurements, we made use of regions of the six distributions lying round their medians, since there are more individuals here and our results thus obtain greater validity. We may now conveniently use the expression σ_{10} for the standard deviation of the transformed distribution of the group 120-131, σ_{11} for that of the group 132-143, and so on. From Table 12 we see that for the 120-131 group the σ_{10} value of a weighted original score of 20 (i.e., the upper limit of the class 17-20) is —.401571, and that the σ_{10} value for the total of 44 (i.e., the upper limit of the class 41-44) is 1.140688. The total difference is thus, 1.542259 σ_{10}. In the case of the group 132-143 a score of 20 points has a σ_{11} value of —.974114, and a score of 44 has the σ_{11} value of .538836. The total distance is thus, 1.512950 σ_{11}. Hence the relation between σ_{10} and σ_{11} is 1.542259÷1.512950, or σ_{11} is 1.019372 of σ_{10}. In the case of the group 131-143 the score of 28 has the σ_{11} value of —.409735 and a score of 52 points has the σ_{11} value of .950221, the difference thus being 1.359956 σ_{11}. In the case of the group 144-155 the score of 28 has a σ_{12} value of —.877896, and a score of 52 points a σ_{12} value of .448212, the difference thus being 1.326108 σ_{12}. The relation between σ_{11} and σ_{12} is thus 1.359956÷1.326108, or σ_{12} is 1.025524 of σ_{11}. Turning to group 144-155 again, Table 12 shows that scores of 36 and 60 have, respectively, σ_{12} values of —.379927 and .816875, the difference thus being 1.196802 σ_{12}. In the case of 156-157, 36 and 60 points have, respectively, the σ_{13} values of —.852386 and .274110, the difference being 1.126496 σ_{13}. The relation between σ_{12} and σ_{13} is thus 1.196802÷1.126496, or σ_{13} is 1.062411 σ_{12}. For the group 168-179 the σ_{14} values of 44 and 72 points are, respectively —.785774 and .588793, the difference being 1.374567 σ_{14}. In the case of the group 156-167 the σ_{13} values of 44 and 72 points are —.462113 and .845199, the difference being 1.307312 σ_{13}. The relation of σ_{13} to σ_{14} is thus 1.374567÷1.307312, or σ_{13} is 1.051445 σ_{14}. Finally, in the case of group 168-179 scores of 48 and 76 have σ_{14} values of —.603765 and .782356. For the group 180-192 scores of 48 and 76 have σ_{15} values of —.874214 and .453762. The two differences are 1.386130 σ_{14} and 1.327979 σ_{15}. Dividing the second by the first, we find that σ_{14} is .958048 σ_{15}.

Making use of the relations found to exist between the sigmas of the six groups, we can express sigma differences of one kind in terms

TABLE 13

MEDIANS OF EACH OF THE SIX BROAD AGE GROUPS IN TERMS OF ORIGINAL WEIGHTED SCORES

Age groups (in months)	Median	Age groups (in months)	Median
120-131	25.184769	156-167	54.556950
132-143	34.834329	168-179	59.836433
144-155	42.886499	180-192	66.258575

TABLE 14

DISTANCES BETWEEN NEIGHBORING MEDIANS OF THE SIX AGE GROUPS, THE DISTANCES BEING EXPRESSED IN TERMS OF σ_{12}

Age groups (in months)	Distance between medians:		
	1st calculation	2nd calculation	Average
120-131 to 132-143	.613545	.593978	.603761
132-143 to 144-155	.449560	.457245	.453402
144-155 to 156-167	.549129	.563143	.556136
156-167 to 168-179	.260296	.282139	.271218
168-179 to 180-192	.297327	.296670	.297098

TABLE 15

DISTANCES IN TERMS OF σ_{12} BETWEEN THE MEDIAN OF THE AGE GROUP 144-155 AND EACH OF THE OTHER BROAD AGE GROUPS

Age groups (in months)	Distance between medians
120-131 to 144-155	–1.057163
132-143 to 144-155	–.453402
156-167 to 144-155	.556136
168-179 to 144-155	.827354
180-192 to 144-155	1.124452

of sigma differences of another kind. It remains only to choose a common point from which the measurements are to be taken. Since the median of the group 144-155 was chosen by us, it is still necessary to determine the differences between the medians of the six age groups. Table 11 gives the (weighted) number of individuals for each of the six age groups together with the original weighted scores. From this data the six medians were calculated. The results are given in Table 13. Using linear interpolation where necessary within each grouping, of four successive original weighted scores, we then determined how far these medians are from each other in terms of σ_{12} as the unit of measurement. A double method of cal-

TABLE 16

Six Independent Determinations of the Sigma Values of Original Weighted Scores, the Values Being Expressed in Terms of a Common Unit and Taken from a Common Point of Measurement

In the first column we have totals (from the lower to the upper limits of the class intervals) in terms of original weighted scores. In the next six columns are given the σ_{12} values of the upper limits of the class intervals for each of the six age groups, measured from the median of the 144-155 age group. In the last column we have the results of averaging the determinations.

Scores in orig. pts. weighted	Values in terms of σ_{12} age groups (in months): 120-131	132-143	144-155	156-167	168-179	180-192	Average
0	−3.686789	−3.667965				−2.398246	−3.538250 [−3.552555]
1-4	−2.871346	−2.905255	−2.878161	−2.971032	−2.577696	−2.250588	−2.864464
5-8	−2.441590	−2.419155	−2.365618	−2.444496	−2.183636	−2.134571	−2.479318
9-12	−2.104022	−2.049390	−2.014091	−2.054461	−1.775264	−1.733785	−2.070030
13-16	−1.723891	−1.704197	−1.684941	−1.696228	−1.606615	−1.600460	−1.709775
17-20	−1.450079	−1.404137	−1.346939	−1.442020	−1.339359	−1.358924	−1.417133
21-24	−1.129683	−1.114778	−1.093897	−1.151404	−1.088059	−1.122629	−1.119119
25-28	−.868845	−.793303	−.877896	−.855304	−.815317	−.891118	−.844996
29-32	−.600963	−.608176	−.618873	−.596380	−.585566	−.674913	−.608752
33-36	−.402612	−.389748	−.379927	−.349439	−.385489	−.464203	−.389371
37-40	−.170159	−.144983	−.156042	−.143813	−.181607	−.233233	−.163267
41-44	.034475	.072502	.060195	.065187	.033408	.013068	.051330
45-48	.225940	.290409	.261120	.239954	.217310	.202415	.243033
49-52	.438842	.474014	.448212	.433363	.421607	.396383	.433505
53-56	.629463	.693385	.628006	.625425	.649146	.634118	.640656

TABLE 16 (*continued*)

Scores in orig. pts. weighted	Values in terms of σ_{12} age groups (in months): 120-131	132-143	144-155	156-167	168-179	180-192	Average
57-60	.802416	.867296	.816875	.847350	.834952	.835348	.836952
61-64	.928473	1.064057	.986271	1.053019	1.015861	1.031802	1.025609
65-68	1.073321	1.255268	1.155221	1.252780	1.230357	1.175888	1.212066
69-72	1.294439	1.411769	1.340755	1.454075	1.422270	1.391657	1.406135
73-76	1.572463	1.639543	1.522036	1.723148	1.617856	1.603035	1.622138
77-80	1.930293	1.897700	1.727934	1.942233	1.815677	1.799739	1.824824
81-84	2.082309	1.998451	1.895698	2.131973	2.050673	2.027271	2.039639
85-88	2.263627	2.355683	2.096927	2.346217	2.260762	2.273388	2.270192
89-92	2.770837	2.562662	2.290370	2.620522	2.540384	2.532078	2.530619
93-96		2.712820	2.575829	2.890533	2.758265	2.839144	2.811137
97-100	3.158422	3.068328	2.878161	3.225038	3.020013	3.140022	3.107734
100-104		3.300821	3.147395	3.613894	3.429972	3.550262	3.510245
105-108			3.956667	4.023944	3.603712	3.982689	3.837307
109-112				4.688872	4.141466	4.309646	4.278471
113-116					4.939682	4.847543	4.891500
117-120							[5.514981]
121							[5.671300]

culation was followed. So, e.g., in the case of the age groups 120-131 and 132-143, we begin with the median of the group 132-143 and calculate in terms of σ_{12} and for the distribution of this group how far 25.184769 (median in original weighted scores of 120-131) is distant from 34.834329 (the median in original weighted scores of 132-143). The procedure is now repeated, only now use is made of the distribution of the group 120-131. We call these procedures the first and the second, respectively. By means of them we get two values for the distance between the medians of any two age groups. Table 14 gives the necessary results. We can now easily calculate what the distances are in terms of σ_{12} between the median of the age group 144-155 and the medians of each of the other groups. These distances are given in Table 15.

We now have all the data needed to express all sigma differences in terms of σ_{12} when measured from a common point, namely, the median of the group 144-155. The results of so doing are given in Tables 16 and 18.

There are still two points to be explained with regard to certain items in Table 16. The first concerns the calculation of average σ_{12} values. As will be clear from Table 8, the total number of tested children of each of the six age groups do not differ much relatively. It was therefore considered unnecessary to introduce any weighting of σ_{12} values on this count when calculating average σ_{12} values. Considerable differences do, however, exist in the reliability of the determinations of the sigma values for the same original weighted totals as obtained from children of different age groups. So, e.g., a considerable number of children in the group 120-131 months old have low original weighted scores, while only a relatively small number of children from the age group 180-192 have these low scores. The converse holds true for high scores. Hence, the reliabilities of sigma values obtained from these two age groups for the same original weighted totals, when very low or very high, may be expected to differ widely. We have taken extreme cases to illustrate the point, but it is clear that the principle applies right through. Hence, in determining average sigma values it becomes desirable to weight each sigma value according to its reliability. To carry out this weighting the percentage of children of each of the six age groups actually tested who obtained any particular score was determined. The data is given in Table 17. Using the formula $\sigma_{f_p} = \sqrt{\frac{f_p(100-f_p)}{N}}$ for the reliability of a percentage the weights

TABLE 17

UNWEIGHTED DISTRIBUTIONS OF THE SIX AGE GROUPS

(Total numbers tested = 16,574)

The first column gives scores, in terms of original weighted totals, from 0 to the maximum of 121 possible on the battery. The next columns give the numbers of individuals tested, in each of the six broad age groups, who reach the scores given in the first column.

Score in orig. pts. weighted	Numbers of children tested in the age groups (in months): 120-131	132-143	144-155	156-167	168-179	180-192
0	8	3				1
1–4	66	23	11	6	5	4
5–8	105	43	31	12	7	2
9–12	124	74	40	30	24	12
13–16	208	105	69	41	23	9
17–20	183	136	103	56	35	16
21–24	250	173	112	71	58	26
25–28	234	187	118	99	70	35
29–32	227	208	167	117	85	42
33–36	166	191	180	136	82	52
37–40	176	224	184	129	111	72
41–44	133	196	192	155	129	89
45–48	116	184	193	146	144	85
49–52	102	141	168	163	170	107
53–56	77	154	158	170	222	141
57–60	54	106	164	206	175	144
61–64	29	99	141	198	198	147
65–68	36	75	113	186	231	138
69–72	29	51	129	182	203	161
73–76	18	58	106	212	208	187
77–80	14	41	108	159	197	169
81–84	8	24	80	128	199	182
85–88	6	21	68	113	167	182
89–92	3	11	52	112	161	166
93–96		6	44	83	124	157
97–100	1	5	19	58	90	116
101–104		2	7	29	80	95
105–108			4	12	28	53
109–112	1	1	1	5	23	20
113–116					5	9
117–120				1	1	1
121						
Totals	2375	2546	2763	3015	3255	2620

TABLE 18

σ_{12} DIFFERENCES BETWEEN SUCCESSIVE σ_{12} VALUES OF ORIGINAL WEIGHTED SCORES

In the first column on the left are given the original weighted score classes for which the σ_{12} differences were determined. The next six columns give the σ_{12} differences for each of the six age groups. Then follows a column giving the average differences and obtained from the data in the last column of Table 16. The results of introducing some slight smoothing to the averages are given in the last column, the smoothed values being used for further calculations.

Scores in orig. pts. weighted	σ_{12} differences between σ_{12} values for the age groups (in months): 120-131	132-143	144-155	156-167	168-179	180-192	Average	Smoothed average
0 to 1- 4	.815443	.762710				.147658	.673790	.688091
1- 4 to 5- 8	.429756	.486100	.512543	.526536	.394060	.116017	.385146	.494175
5- 8 to 9- 12	.337568	.369765	.351527	.390035	.408372	.400786	.409288	.409288
9- 12 to 13- 16	.380131	.345193	.329150	.358233	.168649	.133325	.360255	.360255
13- 16 to 17- 20	.273812	.300060	.338002	.254208	.267256	.241536	.292642	.316970
17- 20 to 21- 24	.320396	.289359	.253042	.290616	.251300	.236295	.298014	.298014
21- 24 to 25- 28	.260838	.321475	.216001	.296100	.272742	.231511	.274123	.274123
25- 28 to 29- 32	.276882	.185127	.259023	.258924	.229751	.216205	.236244	.236244
29- 32 to 33- 36	.198351	.218428	.238946	.246941	.200077	.210710	.219381	.219381
33- 36 to 37- 40	.232453	.244765	.223885	.205626	.203882	.230970	.226104	.220027
37- 40 to 41- 44	.204634	.217485	.216237	.209000	.215015	.246301	.214597	.214597
41- 48 to 45- 48	.191465	.217907	.200925	.174767	.183902	.189347	.191703	.198924
45- 48 to 49- 52	.212902	.183605	.187092	.193409	.195297	.193347	.190472	.190472
49- 52 to 53- 56	.190621	.219371	.178794	.192062	.236539	.237735	.207151	.197973
53- 56 to 57- 60	.172953	.173911	.188869	.221925	.185806	.201230	.196296	.196296
57- 60 to 61- 64	.126057	.196761	.169396	.205669	.180909	.196454	.188657	.188657
61- 64 to 65- 68	.144848	.191211	.168950	.199761	.214496	.144086	.186457	.186457
65- 68 to 69- 72	.221118	.156501	.185534	.201295	.191913	.174069	.190069	.190069
69- 72 to 73- 76	.278024	.227774	.181281	.269073	.195586	.211378	.216003	.202919
73- 76 to 77- 80	.357830	.258157	.205898	.219085	.197821	.196704	.202686	.202686
77- 80 to 81- 84	.152016	.100751	.167764	.189740	.234996	.227532	.214815	.214815

TABLE 18 (*continued*)

Scores in orig. pts. weighted	σ_{12} differences between σ_{12} values for the age groups (in months): 120-131	132-143	144-155	156-167	168-179	180-192	Average	Smoothed average
81- 84 to 85- 88	.181318	.357232	.201229	.214244	.210089	.246117	.230553	.230553
85- 88 to 89- 92	.507210	.206979	.193443	.274305	.279622	.258690	.260427	.260427
89- 92 to 93- 96		.150158	.285459	.270011	.217881	.307066	.280518	.280518
93- 96 to 97-100	.387585	.355508	.302322	.334505	.261748	.300878	.296597	.296597
97-100 to 100-104		.232493	.271839	.388856	.409959	.410240	.402511	.342057
100-104 to 105-108			.809272	.410050	.173740	.432427	.327062	.370094
105-108 to 109-112				.664928	.537754	.326957	.441164	.461164
109-112 to 113-116					.798216	.537897	.613029	.613029
113-116 to 117-120								.623481
117-120 to 121								.156320

were calculated from the data of Table 17, the weights being inversely proportional to $\sigma^2 f_p$. Each sigma value of Table 16 was, therefore, first multiplied by its weight before adding the σ_{12} values of the different age groups, falling in the same row, to find their average value.

Another point with regard to Table 16 concerns the determination of the sigma values of the extremes, namely, an 0-score and high scores of 117-120 and 121 original weighted points. Only three children fell in the group 117-120 of totals, and no child reached 121 points. Taking the case of the children getting a 0-score, we may, firstly, assume that all of them just fell short of getting a total score of one point, and we may then determine the sigma value of this score in the ordinary way from tables of the normal curve. The unbracketed entries over against the 0-score in Tables 12 and 16 were obtained in this way. As shown in Table 16, the average σ_{12} value of a 0-score is then —3.538250. It is clear, however, that there may have been, and probably were, degrees of inability to attain to a score of one point. We therefore calculated the σ_{12} value of a 0-score just below one point by extrapolation. Using the data of the last column on the right of Table 16 the average was found of the five quantities —2.864464 to —1.417133, i.e., of the five average σ_{12} values standing over against the entries 1-4 to 17-20 in the first column on the left of this table. This average is —2.108144. The proportions between these five σ_{12} values were then determined by taking them in sequence and dividing the larger number by the smaller. The four quantities obtained in this way were: 1.15, 1.20, 1.21, 1.20, the mean being 1.19. The quantity —2.108144 was then multiplied by 1.19^3, this giving the product —3.552555 as extrapolated σ_{12} value for a 0-score lying just below an original weighted score of one point. This value is given in Table 16 between brackets. The σ_{12} values obtained for a 0-score by the two methods differ only slightly, but for further calculations use was made of the extrapolated value. The same method was followed in order to get extrapolated σ_{12} values for the score groups 117-120 and 121 points. These are also given between parentheses in Table 16.

The data of Table 16 enable us to find the σ_{12} differences between successive σ_{12} values. The results of the subtractions are given in Table 18. The curves of Figure 7 show graphically what degree of correspondence was found to exist between the six independent determinations of σ_{12} differences. Curves I to VI, being those for the

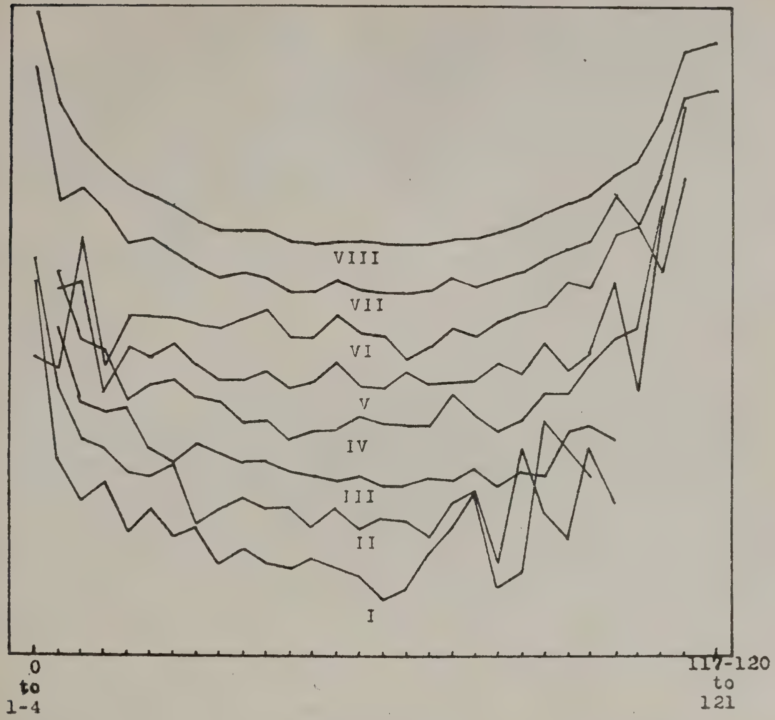

FIGURE 7

Degree of Correspondence Found between Six Determinations of σ_{12} Differences

On the x-ordinate are indicated original weighted totals, equal distances separating successive totals. To facilitate comparison, the curves have been placed above one another. The distances between the successive abscissae are the same. On the y-ordinate is represented the size of the differences. Curves I-VI show the σ_{12} differences for the six age groups taken separately, Curve I being that for the group 120-131, the other curves following in order according to increase of age. Curve VII represents the unsmoothed average σ_{12} differences and Curve VIII the smoothed average σ_{12} differences and the extrapolated values for 0 to 1-4, 113-116 to 117-120, and 117-120 to 121.

separate age groups, show divergencies, but it is also clear that they agree in principle. They agree in showing that changes in the difficulty of obtaining successive original weighted total scores are relatively great in the low and high regions, and that there is a considerable region in the middle where changes in difficulty are, relatively speaking, constant. This is reflected in Curves VII and VIII, giving the unsmoothed average σ_{12} differences and the smoothed average σ_{12} differences. Divergencies between the different determinations of the σ_{12} differences occur especially towards the extremes on the left and the right, where sigma values had, of course, to be calculated from fewer test results than were available for the intermediate region, with the result that there is, on the whole, greater variability and less reliability in their case.

The large amount of agreement existing between the series of six independent determinations with regard to the difficulty values of totals expressed in terms of original weighted scores leads us to consider the second hypothesis, mentioned at the beginning of this section, as true in principle, namely, that the a-normality of the distribution curves of Figures 1 to 6 are, quite in the main at least, due to inequalities in the scale of original weighted totals. We may ask, then, to what extent these distributions become normal if we attach the same (average smoothed) σ_{12} values to identical original weighted scores in each of the six distributions. Figures 8 to 13 show graphically what the results are when this is done, applying the data given in the first and last columns of Table 16 to the weighted distributions of Table 11, the frequencies being calculated for equal distances on the abscissa between the midpoints of class intervals. The values of P, obtained by applying Pearson's chi-square test for normality, are also given. If we superimpose Curves VIII to XIII, we get the result shown in Figure 14. Applying Pearson's chi-square test to the distribution of the combined result, we obtained a value for P of 1. Clearly these results agree with the data and results published by Thorndike.[14]

Following his method[15] in principle, we may now proceed to use the data of Tables 16 and 18 for the construction of a scale of 200 standard points rising with steps of equal difficulty. The sum of the σ_{12} differences given in the last column of Table 18 is 9.314673. This quantity is divided by 200 in order to obtain the σ_{12} differences corresponding to a unit difference on the 200-point scale. The quotient (.046573365) was then divided into each of the σ_{12} differences given in the last column on the right in Table 18, the quotients being the number of units on the 200-point scale for each of these σ_{12} differences. To get the values on our 200-point scale which cor-

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[14] See Thorndike (5, Chap. VIII and Appendix VI).

[15] See footnote 11.

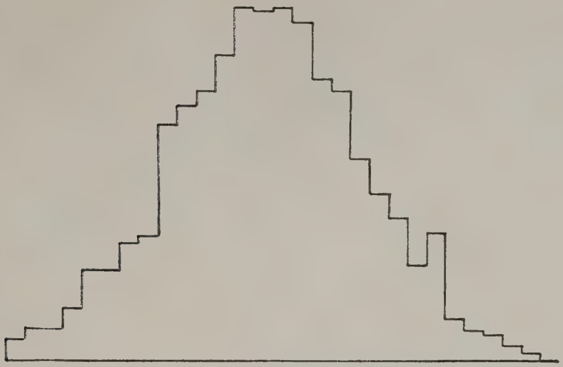

FIGURE 8

Weighted Distribution of Age Group of 120-121 Months When Original Weighted Totals Are Transformed into a Common Scale with Steps of Equal Difficulty, These Being Given Equal Distances on the x-Ordinate

$P = .706743$

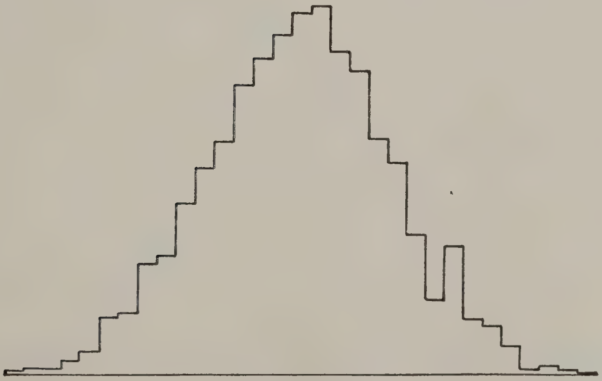

FIGURE 9

Weighted Distribution of Age Group of 132-143 Months When Original Weighted Totals Are Transformed into a Common Scale with Steps of Equal Difficulty, These Being Given Equal Distances on the x-Ordinate

$P = .960390$

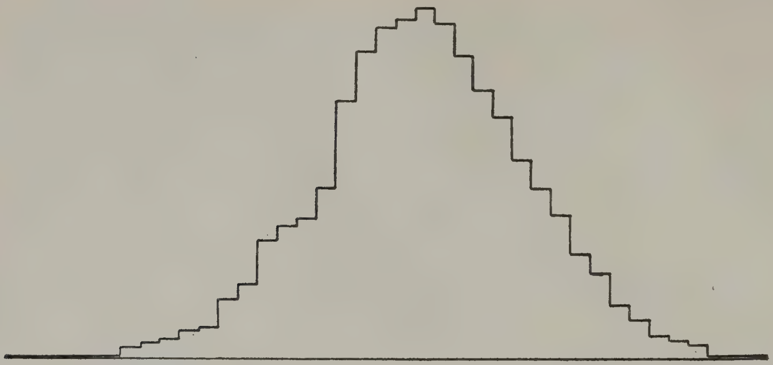

FIGURE 10

Weighted Distribution of Age Group of 144-145 Months When Original Weighted Totals Are Transformed into a Common Scale with Steps of Equal Difficulty, These Being Given Equal Distances on the x-Ordinate

$P = .994765$

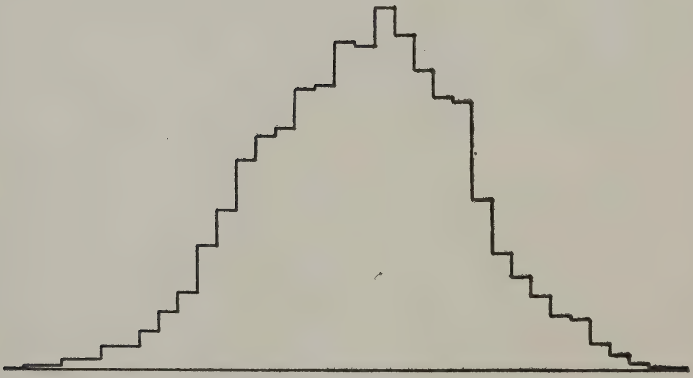

FIGURE 11

Weighted Distribution of Age Group of 156-167 Months When Original Weighted Totals Are Transformed into a Common Scale with Steps of Equal Difficulty, These Being Given Equal Distances on the x-Ordinate

$P = .771782$

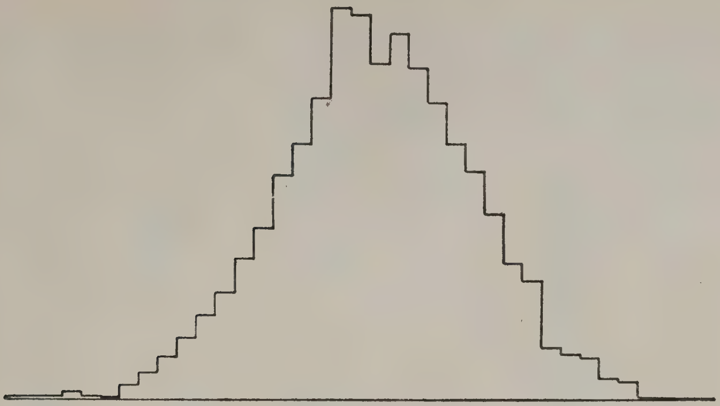

FIGURE 12

Weighted Distribution of Age Group of 168-169 Months When Original Weighted Totals Are Transformed into a Common Scale with Steps of Equal Difficulty, These Being Given Equal Distances on the x-Ordinate

$P = .999615$

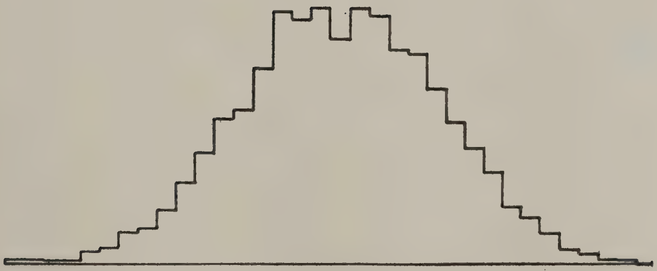

FIGURE 13

Weighted Distribution of Age Group of 170-192 Months When Original Weighted Totals Are Transformed into a Common Scale with Steps of Equal Difficulty, These Being Given Equal Distances on the x-Ordinate

P=.999831

TABLE 19

Relation between Original Weighted Total Scores and Standard Scores

Orig. scores weighted	Standard scores	Orig. scores weighted	Standard scores	Orig. scores weighted	Standard scores
0	0	41	76.65	82	120.08
1	3.70	42	77.80	83	121.24
2	7.38	43	78.95	84	122.40
3	11.08	44	80.10	85	123.64
4	14.78	45	81.17	86	124.86
5	17.44	46	82.24	87	126.10
6	20.08	47	83.31	88	127.34
7	22.74	48	84.38	89	128.74
8	25.40	49	85.40	90	130.14
9	27.58	50	86.42	91	131.54
10	29.78	51	87.44	92	132.94
11	31.98	52	88.46	93	134.44
12	34.18	53	89.52	94	135.94
13	36.12	54	90.59	95	137.46
14	38.04	55	91.66	96	138.96
15	39.98	56	92.72	97	140.54
16	41.92	57	93.78	98	142.14
17	43.62	58	94.83	99	143.72
18	45.32	59	95.88	100	145.32
19	47.02	60	96.94	101	147.16
20	48.72	61	97.94	102	148.98
21	50.32	62	98.96	103	150.82
22	51.92	63	99.96	104	152.66
23	53.52	64	100.90	105	154.64
24	55.12	65	101.99	106	156.62
25	56.58	66	102.98	107	158.61
26	58.06	67	103.98	108	160.60
27	59.52	68	104.98	109	162.96
28	61.00	69	106.00	110	165.34
29	62.26	70	107.02	111	167.71
30	63.54	71	108.04	112	170.08
31	64.81	72	109.06	113	173.37
32	66.08	73	110.16	114	176.66
33	67.26	74	111.24	115	179.95
34	68.43	75	112.32	116	183.22
35	69.60	76	113.42	117	186.59
36	70.78	77	114.51	118	189.94
37	71.96	78	115.60	119	193.29
38	73.14	79	116.68	120	196.64
39	74.32	80	117.78	121	200.00
40	75.50	81	118.94		

respond to original weighted scores intermediate between those for which the σ_{12} values are given in Table 16, we made use of linear interpolation. Table 19 gives us the final results, showing the relation between original weighted totals and our scale of 200 standard points.

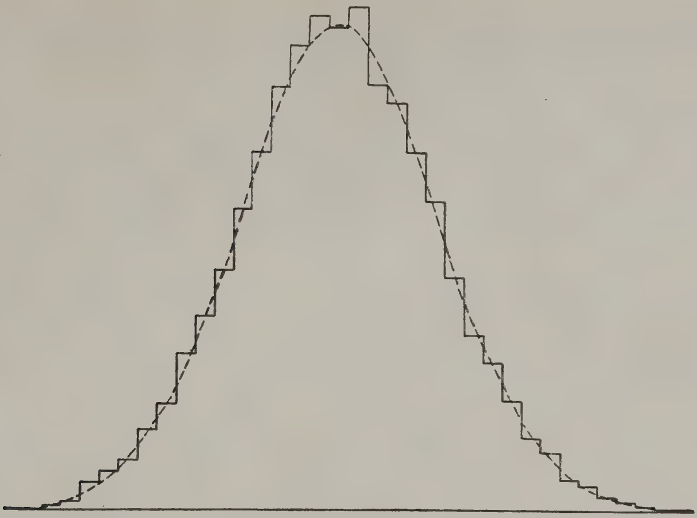

FIGURE 14

Distribution of Intelligence of 16,574 School-going Children When Intelligence is Measured on a Scale with Steps of Equal Difficulty

The distribution is shown as a histogram, an exact normal curve being indicated by the broken line.

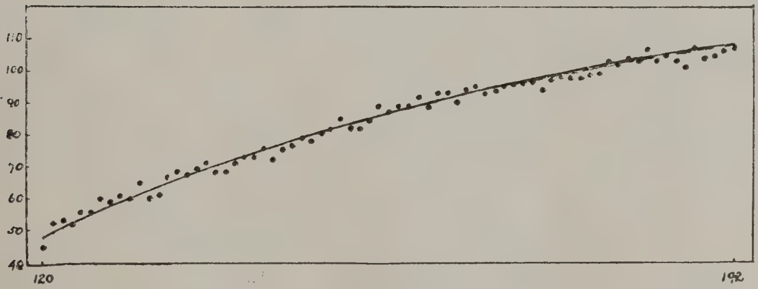

FIGURE 15

Growth of Intelligence from Month to Month from the Age of 120 Months to the Age of 192 Months

Ages are given on the abscissa, the dots showing the average standard scores actually found on the *y*-ordinate. The continuous curve was fitted to these averages.

THE GROWTH CURVE OF INTELLIGENCE AS DETERMINED BY THE SOUTH AFRICAN GROUP TESTS FROM THE AGE OF 120 MONTHS TO THE AGE OF 192 MONTHS

By making use of Table 19 it is now possible to obtain medians, means, and standard deviations in standard points for each of the 73 age groups obtained by dividing the 16,574 children tested into groups of each of which the members are of the same age to the nearest month. In working out central tendencies and variability we made use of the weighted numbers of children previously described. Original weighted totals were translated into standard scores, and medians and means in standard scores were worked out. In doing so we made use of the tabulations of which Table 10 formed an illustration. Reference to Table 10 shows that the children were tabulated in groups according to their performance in original weighted scores, children having a 0-score falling in the lowest group, those having scores of from 1 to 4 points falling in the second lowest group, and so on. For each of these groups the midpoint original weighted score was transformed, by means of Table 19, into the equivalent score in standard points, and each child falling in such group was given the midpoint score expressed in standard points. Medians and average scores in these points were then calculated for the 73 age groups. These results are given in the first four columns of Table 20. The means are represented graphically in Figure 15. The figure shows that there are small irregularities in the growth and these we attribute to chance. We therefore proceeded to fit a curve to the empirical averages. A good result was obtained by means of the hyperbolic curve shown in the figure. The curve was fitted by the method of averages,[16] but equal weight was given to each mean in calculating the curve, in principle by repeating the process and taking the average of the different equations found. This average is $Y = 2\left[\frac{(X-1)}{.1363 + .01433\,X}\right] + 54.22$, where $X = 1$ at 124½ months, and .1 is added (or subtracted) for every month above (or below) 124½ months. The values to be substituted for X in the equation are obtained by taking —.10 for each month below 124½ and .10 for each month above it. Figure 15 shows that the fit of the curve is evidently a close one. To get a

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[16] See Thurstone (6).

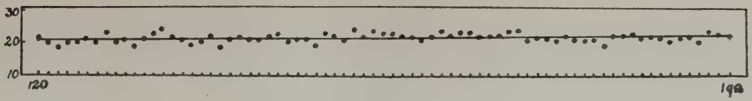

FIGURE 16

INCREASE OF STANDARD DEVIATION WITH THE INCREASE OF AGE FROM 120 TO 192 MONTHS

Age is given on the *x*-ordinate and standard deviations as dots on the *y*-ordinate. The continuous line was fitted by the method of least squares.

numerical value for the goodness of fit we determined the differences in standard scores between the empirical and the fitted averages for each of the 73 groups. These differences were then expressed in terms of the fitted standard deviation (to be described below) of the distribution of each month group. The formula $\dfrac{\Sigma \dfrac{Y - Y}{\sigma_x}}{73}$ gives us a measure of the divergence between empirical and fitted averages. For this measure we obtained the value of .08.

Finally, we wish to add that the standard deviations, round the empirical averages, of the distributions of standard scores show a slight tendency to increase with age. These standard deviations are given in the fifth column of Table 20, and are shown graphically in Figure 16. A straight line was fitted by the method of least squares. The tangent of the angle formed by this line with a horizontal base has the value of .0244147, showing a slight rise with increase of age. Using the formula $\sigma_\sigma = \dfrac{\sigma}{\sqrt{2N}}$ for determining the reliability of the standard deviation of a distribution, and substituting for N the numbers actually tested, we get the values given in column six of Table 20. The standard deviation of the tangent of the angle of the straight line fitted was then calculated, making use of the formula $\sigma_t = \sqrt{\dfrac{12}{m\ (m+1)\ (m+2)}}\ \sigma$,[17] where m stands for the number of determinations (73), and σ for the common standard deviation of the standard deviations of the distributions. For this we used the average of the standard deviations in column six of Table 20, since they differ but little from one another. In this way we get the

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[17] See Pólya (3).

TABLE 20

GROWTH OF INTELLIGENCE FROM THE AGE OF 120 TO THE AGE OF 192 MONTHS

The first column on the left gives the ages in months, the second gives the number tested. Then follow two columns giving the medians and the empirical averages. The next two give the standard error of the distribution of standard scores for each age and the standard error of the distribution. The last column gives the averages on the fitted curve.

Age in months	Number indivs.	Emp. median	Emp. average	$\sigma_{dis.}$	sigma of $\sigma_{dis.}$	Fitted average
120	180	43.3	45.0	21.6	1.1	48.0
121	205	51.6	52.6	19.9	1.0	49.4
122	204	52.7	53.5	18.6	.9	50.8
123	193	52.7	51.8	19.0	1.0	52.2
124	182	55.1	55.85	20.2	1.1	53.6
125	194	56.6	56.3	21.2	1.1	54.9
126	196	60.3	60.0	20.0	1.0	56.2
127	198	62.0	59.3	23.3	1.2	57.5
128	203	62.0	61.1	20.3	1.0	58.8
129	199	65.6	60.1	20.7	1.0	60.0
130	210	64.1	65.5	18.6	.9	61.2
131	213	58.8	60.1	21.1	1.0	62.4
132	246	61.3	60.8	22.7	1.0	63.6
133	197	68.2	67.3	23.9	1.2	64.8
134	214	71.3	68.5	21.5	1.0	65.9
135	210	68.0	67.5	20.5	1.0	67.0
136	216	68.4	69.5	19.1	.9	68.1
137	218	71.4	70.8	20.0	1.0	69.1
138	197	68.0	68.5	21.6	1.1	70.1
139	211	68.7	68.6	18.5	.9	71.1
140	202	69.6	71.2	20.7	1.0	72.1
141	218	70.9	72.85	21.4	1.0	73.1
142	193	73.9	73.3	20.4	1.0	74.1
143	227	76.2	75.6	20.6	1.0	75.1
144	225	71.8	71.9	21.6	1.0	76.1
145	223	76.2	75.4	22.6	1.1	77.0
146	219	75.9	76.5	20.2	1.0	77.9
147	207	76.6	78.9	20.9	1.0	78.8
148	224	75.7	78.2	20.9	1.0	79.7
149	214	78.6	80.2	19.2	.9	80.6
150	248	76.2	81.5	23.3	1.0	81.5
151	234	82.3	84.85	21.8	1.0	82.4
152	232	79.9	82.0	20.5	.95	83.3
153	240	83.4	81.8	24.1	1.1	84.2
154	255	82.8	84.5	21.6	1.0	85.0
155	242	85.5	88.8	23.6	1.0	85.8
156	316	85.9	87.5	22.5	.9	86.6
157	225	89.6	89.3	22.4	1.1	87.4
158	229	87.2	89.2	22.0	1.0	88.2
159	245	90.1	91.4	21.5	1.0	89.0

TABLE 20 (*continued*)

Age in months	Number indivs.	Emp. median	Emp. average	$\sigma_{dis.}$	sigma of $\sigma_{dis.}$	Fitted average
160	296	87.2	88.7	20.5	.8	89.8
161	210	94.1	93.0	21.7	1.1	90.5
162	259	93.9	92.9	23.7	1.0	91.2
163	262	91.3	90.4	21.9	1.0	91.9
164	243	95.0	93.75	23.1	1.05	92.6
165	245	95.4	95.2	22.8	1.0	93.3
166	230	91.2	92.5	21.4	1.0	94.0
167	255	94.1	93.4	21.8	1.0	94.7
168	292	93.8	93.9	22.2	.9	95.3
169	264	93.3	95.4	23.5	1.0	95.9
170	262	96.4	96.2	23.8	1.0	96.5
171	253	96.7	96.6	20.4	.9	97.1
172	261	93.3	94.2	21.5	.9	97.7
173	273	94.1	96.9	21.2	.9	98.3
174	304	96.6	97.8	20.4	.8	98.9
175	288	98.7	97.9	21.9	.9	99.5
176	244	96.8	97.8	21.1	1.0	100.1
177	263	96.7	99.2	20.4	.9	100.7
178	262	98.8	99.4	21.2	.9	101.3
179	289	103.0	102.9	19.0	.8	101.9
180	268	101.8	101.9	22.3	1.0	102.5
181	215	104.7	104.1	22.3	1.1	103.1
182	217	101.7	102.9	23.0	1.1	103.7
183	231	101.2	107.2	21.4	1.0	104.3
184	197	102.7	103.4	21.8	1.1	104.8
185	227	104.3	103.8	21.4	1.0	105.3
186	208	104.9	103.0	20.5	1.0	105.8
187	233	99.5	101.4	21.4	1.0	106.3
188	200	106.4	107.3	22.2	1.1	106.8
189	178	102.1	104.5	20.4	1.1	107.3
190	145	104.6	104.8	24.3	1.4	107.8
191	181	105.3	106.6	23.0	1.2	108.3
192	120	108.3	107.2	22.3	1.4	108.8
				Average =	1.0	

value of .00544 as the standard deviation of the tangent. Since this is considerably less than the value of the tangent itself, the increase with age in standard deviations of the distributions in standard scores must be looked on as statistically reliable.

SUMMARY

The South African Group Test of Intelligence is described with which a research was carried out leading to determinations of curves of the distribution and growth of intelligence. The results are based on the test performances of 16,574 school-going children of European descent in the Union of South Africa who were of the ages 120 to 192 months old. The scaling of the test totals is described, by means of which it was possible to construct a standard scale of totals, successive totals differing by equal steps of difficulty. Using this scale, the distribution of intelligence, as measured by the test, was found to be almost perfectly normal. It is also shown that the growth of intelligence, with increase of chronological age from 120 to 192 months, can be expressed in terms of a hyperbolic equation. The standard deviations of the distributions in terms of standard scores is found to increase slightly with increase of chronological age for the ages mentioned above.

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SUR LA DISTRIBUTION ET LA CROISSANCE DE L'INTELLIGENCE

(Résumé)

Un test collectif de l'intelligence a été décrit, avec lequel on fait une recherche dans l'Afrique du Sud pour déterminer les courbes de la distribution et du développement de l'intelligence. Les résultats sont basés sur le nombre des points de 16,574 écoliers européens, âgés de 120 à 192 mois. On a décrit le traitement des totaux du test, au moyen desquels il etait possible de calculer les totaux étalonnés, qui montent successivement par des degrés également difficiles. En employant ces totaux on a trouvé que la distribution de l'intelligence, measureé par ce test, était presque tout à fait normale. On a démontré aussi que le développement de l'intelligence dans le période entre l'âge de 120 mois et de 192 mois peut être exprimé en termes d'une équation hyperbolique; ainsi que les deviations probables des distributions en termes totaux étalonnés augmentent légèrement en rapport avec l'augmentation de l'âge chronologique de la période ci-dessus.

Wilcocks

ZUR VERTEILUNG UND ENTWICKLUNG DER INTELLIGENZ

(Referat)

Der Südafrikansiche Gruppentest der Intelligenz wird beschrieben. Es wurde mit diesem Test eine Untersuchung ausgeführt zur Feststellung der Verteilung und der Entwicklung der Intelligenz. Die Ergebnisse beruhen auf Testleistungen von 16,574 Schulkindern Europäischer Abstammung in der Südafrikanischen Union vom Alter 120 bis 192 Monate. Eine standard Punkt-skala für individuelle Gesamtleistungen wurde ausgearbeitet, wonach aüfeinanderfolgende Gesamtzensuren gleichgrosse Schwierigkeitsunterschiede bekommen. Beim Gebrauch der Punkt-skala stellte es sich herauss, dass die Verteilung der Intelligenz beinahe vollkommen eine normale war. In Bezug auf die Entwicklung der Intelligenz von 120 bis 192 Monaten wird die zusammengefasst als hyperbolische Funktion des Alters. Beim Wachsen des Alters vergrössert sich auch, obwohl nur in geringem Masse, die Standard Abweichung der Verteilung der Testleistungen, wenn sie nach der Punkt-skala gemessen werden.

WILCOCKS

SPECIFIC AFFERENT IMPULSES AND CUTANEOUS SENSIBILITY*

From the Department of Biology of Clark University

Hudson Hoagland

I

The status of the doctrine of "specific energies" of nerves has undergone many vicissitudes since its systematic presentation by Johannes Müller in his *Handbuch* published in 1838. The history of the doctrine has recently been reviewed by Boring (6) and it is sufficient here merely to note its extensive and varied use by both physiologists and psychologists to account for the attributes of quality in sensation down to the present time. While most writers, in view of accumulating evidence, have favored a central locus for the specificity, a subject upon which Müller did not commit himself, other workers have regarded the peripheral nerve fiber as the conductor of a peculiar physiological concomitant of sensory quality. This latter view became increasingly unpopular with the development of methods for the electrical recording of nerve impulses in which it appeared that all impulses were accompanied by similar action potentials, not only in sensory and motor nerves, but in different kinds of sensory nerves as well.

Adrian (1), in his book, *The Basis of Sensation,* published in 1928, summarizes this point of view in the light of numerous experimental considerations involving the measurement of electrical discharges in afferent nerves. While finding frequency of response the apparent concomitant of intensity of sensation, he failed to discover differences in impulses which would account for quality. The action currents set up in nerves by pressure on the skin, by stimulating receptors in muscles, and even by thrusting a needle into the skin are all similar, the responses of the several receptors differing only in their times of adaptation. This, for example, led Adrian to suggest that the only observable difference in the electrical responses due to "painful" stimuli from those responses aroused by pressure is in a certain "massive-

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*Accepted for publication by Carl Murchison.

ness" of response in the case of the former. The thrust of a needle into the skin apparently produces a response of fairly high frequency from many fibers which maintains itself over a relatively long time before being greatly reduced by adaptation.

Much work on the nature of the punctate distribution of warmth, cold, pressure, and pain in the skin has tended away from the notion of the correlation of these specific qualities with the responses of specific sense organs under the spots (8, 9, 15, 16, 20). Maps of skin spots giving sensory qualities have been found, notoriously, not to correspond to distributions of special encapsulated sense organs in the skin as histologically determined after dissecting away the mapped region. Waterson (21) finds that, while at single examinations of "hot and cold spots" a punctate distribution prevails, this distribution varies considerably from time to time in the same individual. He also reports that in conditions of mild erythema the sensation of heat can be obtained from practically all points of the affected surface at a single examination. Apparently, therefore, all parts of the surface are potentially sensitive to heat and there is no punctate arrangement of special receptors and special nerve fibers for thermal sensation. Nafe (19) has quite abandoned what he calls "qualitative" theories of feeling in favor of a "quantitative" theory. He rejects the doctrine of "specific energies" of nerves in favor of a correlation of aspects of skin sensibility with certain patterns of excitation depending in part on local conditions in the skin and in part on the reflex excitation of central processes arising from the quantitative relations of frequency patterns from the skin. He cites considerable evidence tending to show that all of the so-called qualities of feeling, warmth, cold, pressure, pain, tickle, itch, etc., may be aroused by varying the intensive patterns of stimulation, as, for example, in the case of the experience of heat from the "heat-grill" of Cutolo.

In 1928 probably the most generally accepted form of the doctrine of "specific energies" of nerves in the case of cutaneous sensibility was to regard the skin as possessing both free nerve endings and special encapsulated endings such as Krause bulbs, Pacinian corpuscles, hair cells; the various structures differing in receptive sensitivity to energy changes in their environment and in their ability to produce differing durations of excitatory states. The notion of specific, peripheral, afferent impulses as the correlate of sensory qualities was at a very low ebb indeed. This point of view was substantiated by Adrian and Umrath (5) who recorded the action potentials from single Pacinian corpuscles of the cat. They write:

> "The discharge of a single mammalian sense organ is of the same type [as that from receptors in frogs' muscle and skin and in the cat's toe pad] and for normal stimulation covers approximately the same range of frequency as that of the sense organs in the frog and of the motor neurones of the spinal cord excited reflexly and voluntarily. It is suggested that the character of the discharge is determined by some property common to all neurones which have a medullated axon, the reaction being the same whatever the nature of the stimulus."

Evidence for a certain degree of specificity of impulses in peripheral sensory nerves came about with the work of Erlanger, Bishop, and Gasser (10) in 1926. These workers found that the action currents of afferent nerves, initiated by electrical stimulation, were, in many instances, of a compound nature after travelling appreciable distances from the source of stimulation. They showed, by recording with a cathode ray oscillograph, at different distances along the nerve, that catacrotic waves are produced by fibers which conduct at different velocities and so get out of phase with each other. They discovered, initially, three waves which they labelled α, β, and γ, all fused at the origin but separating in a given nerve trunk at varying distances from the point of stimulation. They were able to show a direct proportionality between size of fiber and speed of conduction both in mixed mammalian nerve and in frog nerve. The sensory roots were found to contain fibers varying considerably in diameter and showing catacrotic waves while the motor nerve fibers were of uniform size and gave uniform action potentials. The motor root of the ninth nerve of the bullfrog, for example, is of a fairly uniform histological structure, with the bulk of the fibers of about 15μ in diameter; the sensory root, on the other hand, is heterogeneous, containing fibers from 20μ to 3μ. In the first case the action current of simple form, while in the latter case α, β, and γ components, appear. By gradations of stimuli it was possible to excite selectively certain of the fibers and not others, indicating different relations of chronaxie for different fiber sizes. By the procedure of analyzing the total response of the nerve to electrical stimulation, Erlanger, Bishop, and Gasser showed that the sensory fibers from muscle are larger and conduct more rapidly than those from the skin. Matthews (18), working in Adrian's laboratory, confirmed the differences in impulses from frog's skin and muscle, using end-organ instead of nerve-trunk stimulation, and recording the action currents in individual nerve fibers. Erlanger (12) has suggested that the time relations of the afferent impulses may serve as a basis for their assortment in the central nervous system due to the existence of intramedullary receptors tuned to respond selectively to impulses of specific form.

By further improvements in the technique of electrical recording, Erlanger and Gasser (11) in 1930 showed that, in addition to the original group of catacrotic waves, there are others, both in frog and in mammalian nerve, which they call B and C waves, of greatly reduced potential, which travel much more slowly than those of the A group. To quote:

> "In round numbers the range of conduction of the fibres contributing to A [a summed wave containing the original α, β, and γ waves] in the dog and cat is 40 to 30 meters per second, of the B fibres 20 to 10 m.p.s., of the C fibres 1.6 to 0.3 m.p.s.; in the bullfrog the ranges are for A, 50 to 10 m.p.s., for B, 5.5 to 1.3 m.p.s., and for C, 0.9 to 0.2 m.p.s...... The A elevation always is compound, B occassionally so and C usually. In the sciatic of the bullfrog at the usual distances of conduction the amplitudes of the elevation [of potential] relative to C (=1) in round numbers, typically are, 5 and 100 for B and A respectively, in the skin nerve of the bullfrog the relative heights may be 1, 3 and 40 and in the saphenous of the dog (a skin nerve) 1, 4 and 40 for C, B and A respectively."

A number of fibers from dorsal and ventral roots of the frog and of the dog were examined by Erlanger and Gasser for B and C waves, but no sharp anatomical or histological classification was found to apply to them although they occurred predominantly in small dorsal root nerves. As in the case of α, β, and γ waves, graded stimuli could be used which would just elicit the A group, the B group, or the C group. In general, the A fibers are those that produce the familiar action potential in which previous work had disclosed the α, β, and γ waves; they include the large myelinated fibers down to about 5μ. The B and C fibers include the myelinated fibers not included in the A group and the unmyelinated fibers.

Adrian (2), in 1930, using a Matthews (17) amplifier and oscillograph, obtained records of slow nerve impulses corresponding to the C type of waves from the dorsal cutaneous nerves of decerebrate frogs on stimulating the skin with dilute acetic acid. Touching the skin gave rapid impulses with large action potentials, while the acid gave both rapid (A type) and very slow impulses with small action potentials (C type). Adrian regarded the slow type of impulses as a correlate of the "common chemical sensation" (7) and concludes against the specificity of these impulses for "pain" since protective reflexes similar to those aroused by acid stimulation may be produced by an induction shock applied to a nerve that initiates impulses of the rapid type.

Adrian, Cattell, and Hoagland (4) in 1931 in a further study of the action potentials from the dorsal cutaneous nerves of frogs showed that stimulation of a skin area by an interrupted jet of air which had been demonstrated to produce a "massive" discharge in the nerve of high frequency and slow adaptation time failed to produce struggling reflexes on the part of intact or decerebrate frogs. The lack of reaction on the part of intact frogs exposed to the air jet, despite demonstrated "massiveness" of discharge, modifies the earlier suggestions of Adrian concerning the nature of the afferent neurological basis of the response to "painful" stimuli. It was also shown that impulses similar to those produced by chemical irritants on the skin could be initiated by scraping, crushing, or burning the skin. To quote these authors:

> "The great difference between these slow potential waves and the large rapid waves of the tactile discharge may be seen in [Figure 1 of this paper]. A limited area of the epidermis was

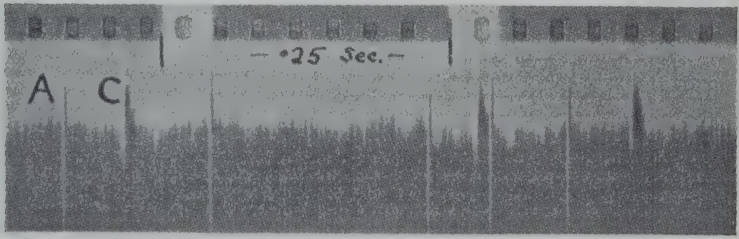

FIGURE 1

Slow Impulses Due to Injury and Rapid Impulses Due to Tactile Receptors

Electrodes 5 mm. apart on dorsal cutaneous nerve cut proximally. Epidermis scraped away from part of the receptive area. The rapid impulses are produced by touching the intact skin. The first rapid impulse is marked A and the first slow impulse C. The base line shows small, irregular movements due to the amplifier. (Reproduced from the *Journal of Physiology*.)

> removed with a knife a few minutes before the record was made, and at the moment of recording an undamaged part of the receptive field was touched with a brush to produce the tactile impulses. Owing to the high amplification, the base line shows the usual small irregular fluctuations which are caused by the unsteady emission of the first valve, but the slow waves can be clearly distinguished by their uniform size and shape. They are diphasic, but owing, probably, to the varying cross-section of the nerve, the first phase is less prominent than the second. In the rapid waves the two phases follow one another so closely that each response appears as a narrow vertical line, but the deflection is very much larger in spite of the interference of the effects at the two electrodes. The great difference in time relations suggests that the fibers responsible for the slow waves belong to the C group of Erlanger and Gasser. As they have shown, the fibers of this group have many of the properties which we should expect to find in a system concerned with pain, though it is unlikely that it is the only system concerned, since there is evidence that some pain reactions are evoked by fibres which conduct more rapidly."[1]

It appears from the above discussion that improvements in methods of electrical recording in recent years have resulted in the accumulation of a convincing body of evidence in favor of the existence of quantitative specificity of afferent nerve impulses, which, in some instances, appear to be correlates of specific sensory qualities. The quantitative differences which are at the basis of the specificity of the impulses may, as has been suggested (12), serve as at least a partial basis for the sorting of impulses by central mechanisms, thereby throwing the ultimate basis of quality back on the central nervous system. But, granted this, a return to what a few years ago would have been regarded as perhaps a naïve form of the doctrine of specific energies of nerves appears to be justifiable.[1a]

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[1] Erlanger and Gasser have suggested that the C fibers may be concerned with protopathic sensibility.

[1a] Adrian's Croonian Lecture (*2a*) did not come to my attention until this paper was in proof. Adrian continued the study of the slow and fast fiber systems both in the frog and in mammals. The results from the frog are least equivocal. Touch gives A-type impulses similar to those recorded in Figure 5 of this paper. Frog skin scraped with a knife to remove external layers may give only C-type impulses when crushed in a clamp. Burning gives predominantly C-type impulses. Adrian did not study the responses of single fibers supplying individual pressure and "pain" spots (as is done in Section III of this paper), but his conclusions from the effect of various

II

The following experimental procedure is essentially a continuation of the method described by Adrian, Cattell, and Hoagland (4). These workers exposed the dorsal cutaneous nerves of the frog by a dorsal median incision of the skin and tied the central end of the nerve with a thread. The nerve was then cut close to its entrance into the muscles and drawn by means of the thread across silver, silver chloride electrodes and the action potentials initiated by stimulating the skin were recorded by means of a standard Matthews oscillograph and valve amplifier (17) used with a suitable camera. Part of the amplified potential was converted into sound (3) by the use of a loud speaker, and, in addition, some of the light from the oscillograph mirror was deflected by a system of prisms and lenses and focused upon a rotating mirror of the type described by Forbes (13). From the rotating mirror the light was thrown on a screen so that the impulses could be viewed. By lightly stroking the skin with a feather one could hear the impulses by means of the loud speaker and map the distribution of the nerve to a specific area of the skin. Figure 2 is the reproduction of a figure from the *Journal of Physiology* showing a distribution map for four dorsal cutaneous nerves of which there are generally five on a side. It will be seen that there is considerable overlap of the areas supplied by the nerves.

If, instead of cutting the nerve of a decerebrate or spinal frog where it enters the musculature of the back, one cuts the nerve at its entrance to the skin and draws it over nonpolarizable electrodes, leaving its central connection intact, one sometimes obtains action potentials in response to touch from small specific areas of the skin, which, by the uniformity in size of the potentials and by their time relations, show themselves to be those of single nerve fibers (1). These impulses are antidromic impulses due to an axon "reflex" since they persist after pithing the cord and destroying the sympathetic nervous system. The axon or antidromic reflex results from the fact that one of the afferent neurons branches in the dorsal root ganglion and sends a fiber not only along the dorsal cutaneous nerve but also a fiber along one of the other nerve trunks running from this ganglion

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types of graded sense-organ stimulation in producing specific nerve impulses when recorded from the nerve trunk are in essential agreement with those arrived at in the present paper. Adrian's paper also contains interesting speculations concerning the central determinants of pain and touch.

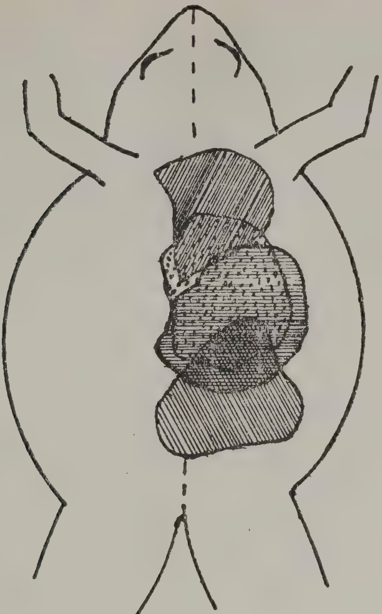

FIGURE 2

DISTRIBUTION OF TACTILE ENDINGS SUPPLIED BY FOUR DORSAL CUTANEOUS NERVES IN A TYPICAL EXPERIMENT

(Reproduced from the *Journal of Physiology*.)

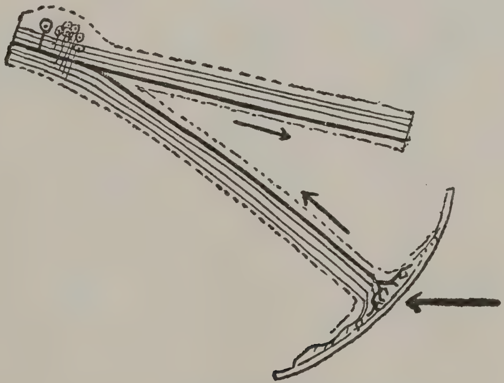

FIGURE 3

ARRANGEMENT OF NERVE FIBERS GIVING THE ANTIDROMIC DISCHARGE

(Reproduced from the *Journal of Physiology*.)

and supplying other regions of the skin. Figure 3, reproduced from the *Journal of Physiology,* illustrates this arrangement of fibers giving the antidromic discharge and Figure 4 shows two typical spots which give rise to antidromic responses in a particular frog. Each of these spots corresponds to the area of distribution of an individual nerve fiber and may be contrasted to the larger areas illustrated in Figure 2 corresponding to the gross distribution of the dorsal cutaneous nerve trunks. These nerve trunks were found, on histological examination, to contain 50 ± 5 fibers of varying diameters.

The receptors producing antidromic reflexes usually gave uniform action potentials characteristic of single nerve fibers, though occasionally two and, very rarely, three fibers have been involved from one spot. The anatomical areas of the spots remained fixed in a given preparation despite radical physiological changes produced in the frog. The skin was pinched, epinephrin and strychnine were injected, and the entire spinal cord was pithed without changing the position or size of the spot. This constancy of area was also characteristic of the gross region supplied by a nerve as well as of that supplied by a single fiber. The sensory endings in the frog's skin are primarily of the free-nerve-ending type (14), though a relatively few terminations may be encapsulated endings. Antidromic spots from which impulses are initiated in single fibers vary in area from between 2 to 100 sq. mm. while the area supplied by a dorsal cutaneous nerve varies from 50 to 200 sq. mm. (Figures 2 and 4).

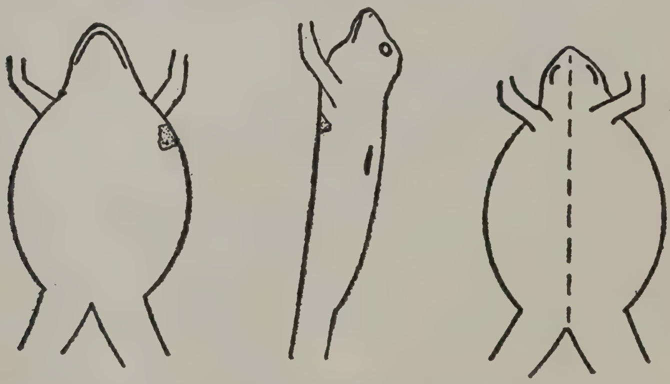

FIGURE 4

AREAS GIVING AN ANTIDROMIC DISCHARGE IN A DORSAL CUTANEOUS NERVE IN ONE EXPERIMENT

Each area shows the distribution of tactile endings from a single nerve fiber. (Reproduced from the *Journal of Physiology.*)

III

With an apparatus similar to that used by Adrian, Cattell, and Hoagland, the writer has continued the study of responses in the dorsal cutaneous nerves of the frog (*Rana temporaria*). Using four frogs with brains and spinal cords pithed, ten areas of distribution of dorsal cutaneous nerves responding to the light touch of a feather were mapped in the manner described above. Figure 5 I shows photographs of impulses initiated by lightly stroking the skin of a preparation with the tip of a feather. The nerve had been cut at its entrance to the dorsal muscles and drawn over electrodes. The bursts of impulses each correspond to a stroke of the feather. They appear as groups of faint vertical lines in the figure.

Each of the ten areas mapped for touch for a given nerve was found to correspond very closely to the distribution of the area sensitive to acid stimulation. Pieces of filter paper soaked in 20% acetic acid were applied to the skin. The gross areas supplied by any one nerve sensitive to the feather were also sensitive to acid as judged by the burst of impulses from the loud speaker which continued for several minutes after removal of the acid-soaked paper. This is in agreement with findings of Adrian (2*a*). The responses were produced by the chemical irritant since water on filter paper elicits no impulses aside from an initial one or two set up by the slight movement of skin caused by putting the paper on it. Adaptation to constant pressure is very rapid (6*a*). Washing the skin with a jet of water from a wash bottle stopped or substantially reduced the impulses initiated by the acid. The borders of the areas sensitive to touch corresponded closely to those sensitive to acid. In a few cases the area responding to touch seemed to be slightly greater than that responding to acid but this may have been due to slight movement of the skin caused by pressure of the feather. The small discrepancies of areas are apparently not significant. Figure 5 II shows two types of impulses, one initiated by movements of the skin and the other by acid stimulation, as is explained in the legend of the figure.

Preparations were examined for antidromic reflexes set up in response to acid stimulation. Nerves were cut near their entrance to the skin and the skin was explored by touching it with squares of acid-soaked filter paper. Usually no response occurred, but in about one-fourth of the preparations examined impulses were produced in response to the acid which, when viewed on the screen or from photographic records, appeared to be single fiber impulses.[2] Sometimes two different antidromic "reflexes" were initiated in the same nerve from widely differing spots, one spot responding to touch and *not* to acid and the other responding to acid but *not* to touch. Typically, in such cases the failure of the "touch" spot to respond to acid was clearly not the result of the destruction of the ending by the acid, since, though inactive during exposure to the acid, the spot would respond to light touch both during the exposure and after the acid had been washed away by a stream of Ringer's solution from a wash bottle. Typical "acid"-sensitive spots, on the other hand, were usually found not to respond at all to light mechanical stimuli, although crushing the skin at the spot would frequently elicit responses. Prolonged exposure to 20% acetic acid will anaesthetize both types of receptors. The rate of anaesthetization is very variable, being roughly as much as four minutes in two cases and as little as 10 seconds in one case. The mean time of anaesthetization for fifty cases of both types of endings was roughly in the neighborhood of two minutes.

Figures 6 I and II show responses recorded from two fibers in the same nerve, I, those initated by touching (lightly brushing with the tip of a feather) an antidromic spot and II, those initiated by acid. In this case the stimuli were entirely specific, the spots were separated by several centimeters. The camera was running slowly so that the differences in the durations of the impulses as recorded photographically are not conspicuous. It is apparent that the duration of the impulses is greater in II—the potential spike is much thicker. The impulses from the individual touch receptor are of slightly higher potential and appear narrow in the photograph, indicating short duration as compared to those from the individual receptor responsive to the acid.

Out of 45 antidromic reflexes examined in 20 frogs, 32 were found to respond only to touch and not to acid and 13 were found to respond only to acid and not to touch.[3] In 10 other cases the same antidromic area gave impulses in response to both types of stimulation, although

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[2] Occasionally two and very rarely three fibers may be found to be active from an antidromic area. This is true for both areas sensitive to touch and those sensitive to acid.

[3] This distribution may not be proportional to the distribution of specific receptors in the skin since the measurements were made on antidromic reflex preparations and there may be no direct proportionality between the occurrence of branching fibers and the dermal distribution of the specific endings.

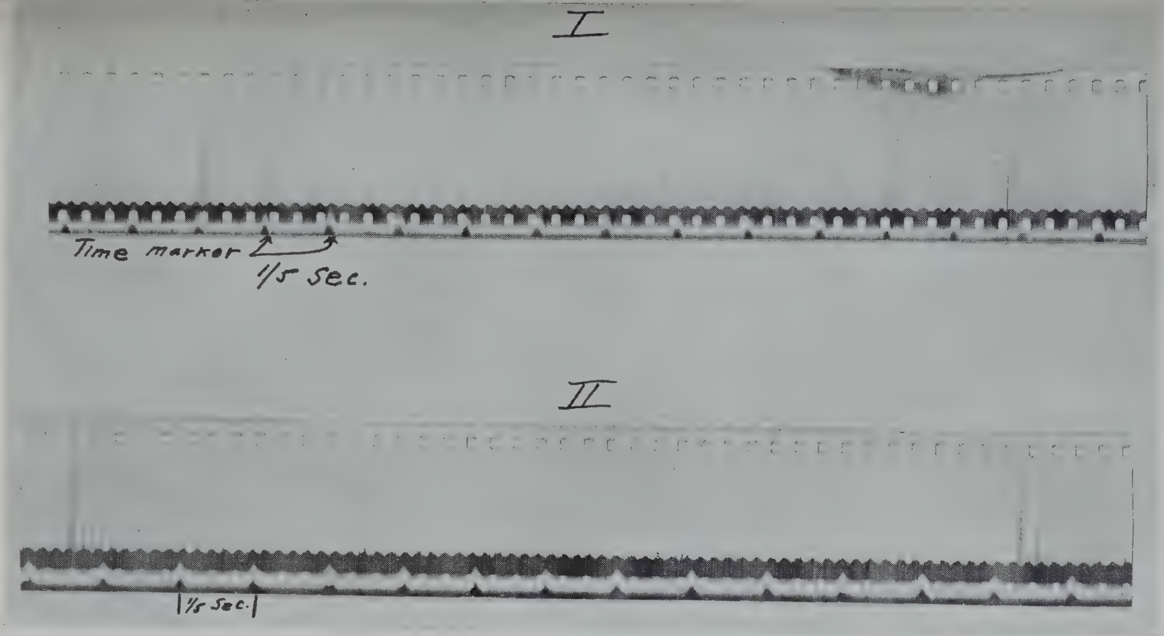

FIGURE 5

I. Impulses, A type, initiated by touching the skin supplied by a dorsal cutaneous nerve. The impulses appear as faint groups of slender spikes. The nerve was cut proximally at its entrance to the muscles and drawn across electrodes. The skin, supplied by the nerve, was lightly stroked with the tip of a feather. The waves in the base line are due to vibrations of the camera motor. The height of the potential spike is directly proportional to the action potential—the thickness is proportional to the duration of the impulse.

II. The two large bursts of impulses on the extremes of the record are produced by breathing movements of a frog which had been pithed in such a way as to leave its respiratory center intact. The movement of the skin sets up the bursts in the dorsal cutaneous nerve (cut centrally). The skin had been painted with acid a minute previously and the small random impulses scattered across the record are typical of the C type of impulses usually set up by acid. The figure is a remarkable example of the type of specificity sometimes found. A-type impulses frequently initiated by acid had adapted out at the end of a minute. The A-type response to the breathing movements continued for half an hour. The acid was washed off after taking this photograph.

The speed of the camera is constant and the amplification is the same in Figures 5, 6, 7, and 8.

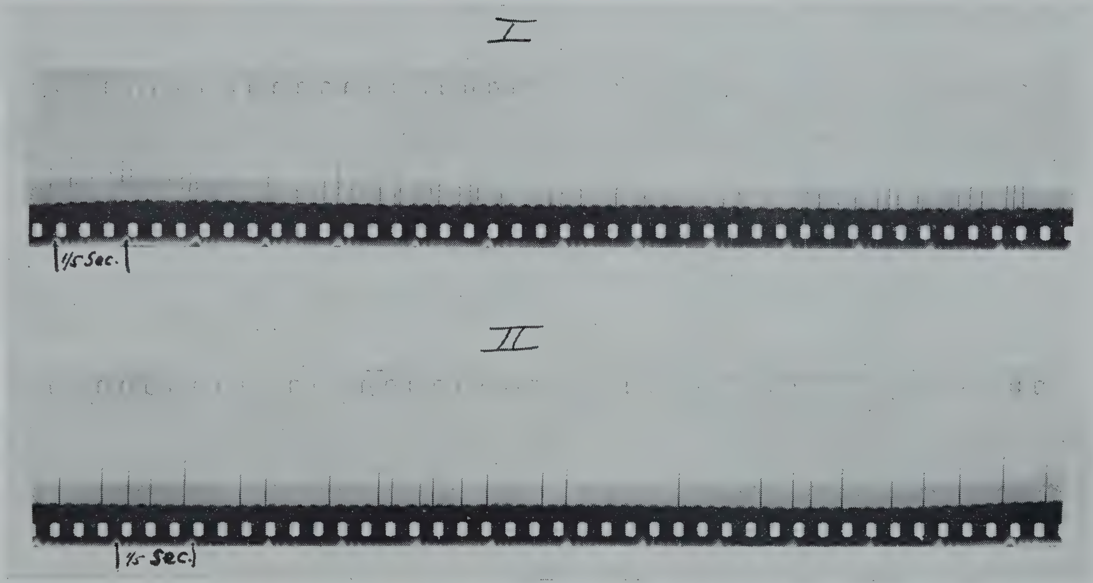

FIGURE 6

Records of Impulses Obtained from Two Fibers from Different Antibromic Spots in the Same Dorsal Cutaneous Nerve (Cut Near Its Entrance to the Skin)

I. Single-fiber impulses initiated by rapidly brushing the skin with the tip of a feather. Response not elicited by acid.

II. Single-fiber impulses initiated by the application to the skin of filter paper soaked in 20% acetic acid. Response not elicited by touch.

The impulses in II are clearly of longer duration—the spikes are thicker. The screen showed them to be of approximately five times the duration of the impulses shown in I.

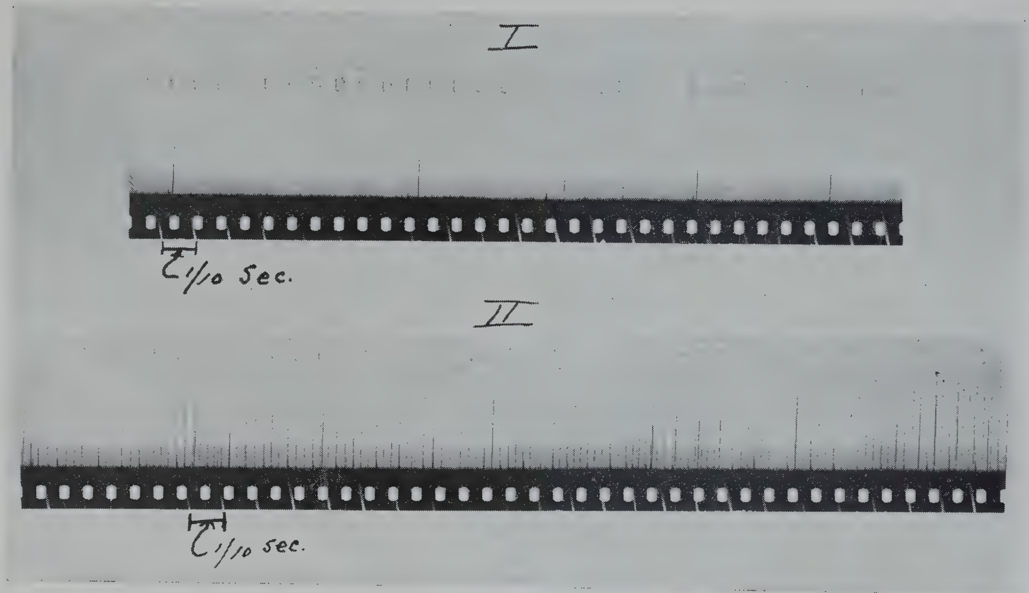

FIGURE 7

ANTIDROMIC RESPONSES TO BOTH TOUCH AND TO ACID ELICTED IN THE SAME NERVE BUT IN DIFFERENT FIBERS FROM APPROXIMATELY THE SAME SPOT

I. Response to vigorous stroking with the blunt quill of a feather. Two fibers are evidently active.
II. Responses elicited by acid-soaked filter paper (20% acetic acid). Two fibers active. The uniform frequency of discharge of one of the receptors is interesting. The fibers responding to acid in this case are apparently of the A type, an exception to the general rule.

The fibers whose potential is recorded in I did not respond to acid. Those recorded in II did not respond to stroking.

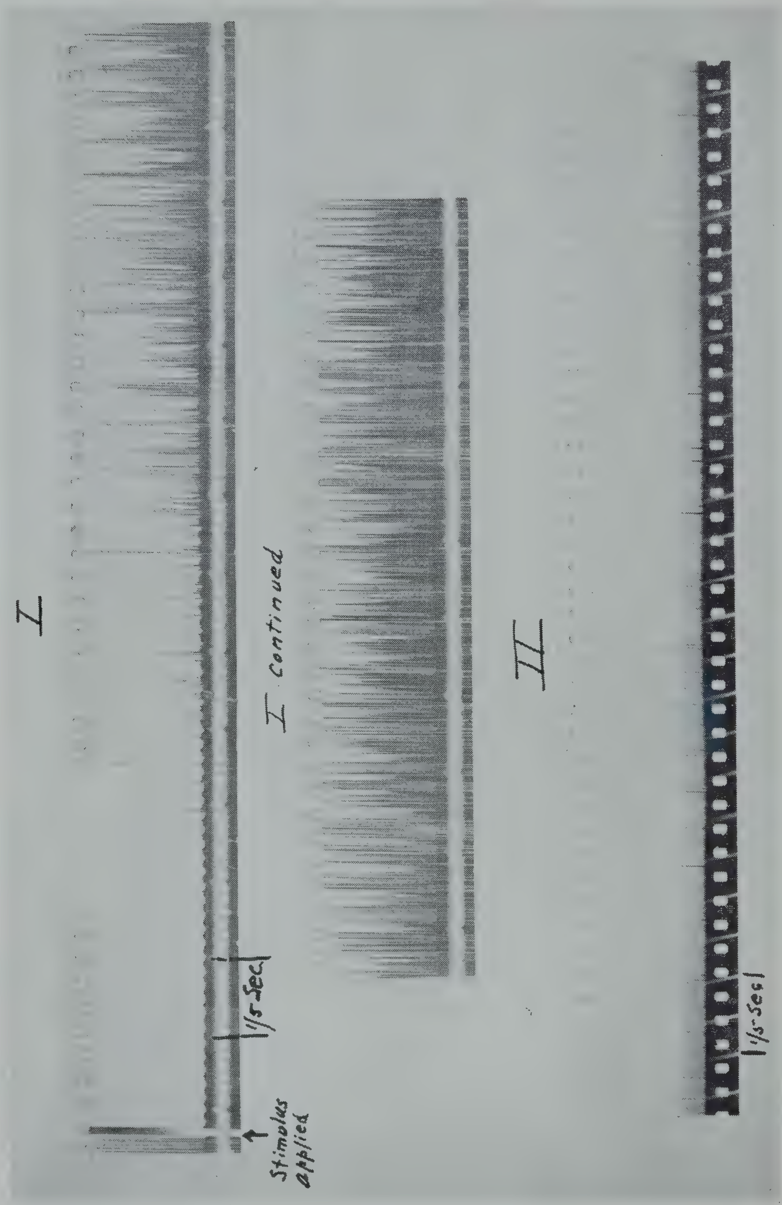

FIGURE 8

I. Gross response of a dorsal cutaneous nerve to 20% acetic acid.

II. Gross response of a dorsal cutaneous nerve to a red-hot soldering iron clamped 3 millimeters from the skin.

The impulses in both I and II are a mixture of the rapid and slow types. Cooling the skin with ice produces no detectable nerve impulses.

these may have resulted from different fibers supplying the same antidromic area (cf. Figure 7). In four instances, however, the impulses set up by the two forms of stimulation seemed to be identical when viewed on the screen, in which 3 centimeters is equivalent to 1/60 second.

Figure 7 shows impulses from an antidromic area which gave responses both to touch and to acid. The responses to touch (I) in this case were elicited only by harsh stroking with the blunt quill end of the feather and they are of the slow type with relatively low potential. There are evidently two antidromic fibers active from the same general spot. With the application of acid to the same spot, Figure 7 II was obtained. The record indicates the response of two fibers to the acid and these, as judged by their potentials, are evidently not the same fibers that are responsive to touch. The potential of the two fibers is higher than in either of the responses shown in Figure 7 I, and the duration of the response is less. Quantitative time relations which are indicated by the thickness of the potential spikes on the records are shown clearly on the projection screen at the time of the experiments. The responses recorded in Figure 7 are unusual in the sense that most impulses initiated by acid on antidromic spots are of the slow, low-amplitude type which, as a rough approximation, may be spoken of as of the B or C types, while impulses aroused by touching the skin are generally of the rapid, high-amplitude, A type (cf. Figures 5 II and 6). This classification of types holds roughly in 75% of the single fibers examined, the remaining cases not adhering to this rule. The results shown in Figure 7 are precisely the opposite of the rule, although here the necessary harsh stroking may have been the equivalent of a stimulus which would elicit struggling reflexes in the intact frog. Figure 8 I shows gross typical responses to acid on the skin recorded from a dorsal cutaneous nerve (cut centrally). Both fast and slow impulses are in evidence. Figure 8 II shows the (gross) response of a dorsal cutaneous nerve when a red-hot soldering iron is held a few millimeters from the skin. There are apparently only 3 fibers, out of a possible 50, that are responding. This is quite typical. Moderate warming of the skin was found to elicit no response and even the response to scorching —in this case the skin was actually dried by exposure to the heat for 30 seconds—occurs in only a few fibers. It seems probable from the excessive temperatures required to elicit responses that the frog is insensitive to normal changes of temperature in its environment;

only thermal stimuli which actually result in destructive changes appear to produce nerve impulses. These responses may be of the rapid or slow type, but are predominantly of the latter class when viewed on the screen.

As judged by the shape of the impulses on the screen, single fibers responsive to intense thermal stimulation often appear to be also responsive to acid stimulation, although most of the fibers responsive to acid stimulation are insensitive to even intense thermal stimuli (cf. Figure 8). Most of the fibers responsive to light touch are not responsive to either acid or intense thermal stimuli as indicated by the previous protocols.

IV

Frog's skin apparently contains two types of receptors. One type is sensitive to light touch and is usually insensitive to other forms of stimulation, and the second type is sensitive to that class of stimuli which produce struggling movements in the intact frog and which in man would be called painful stimuli. These receptors are usually insensitive to touch. For the most part, the action potentials initiated in fibers responsive to touch are large and come and go very rapidly, while the potentials initiated by the "painful" stimuli are of less amplitude and of longer duration. However, some of the fibers examined are evidently set into activity by both classes of stimuli, and, as may be seen in Figure 7, the temporal relations, and the potential amplitudes may, in some instances, be the reverse of those normally found. It is apparent that no sharp line can be drawn between touch receptors that give *only* A-type impulses and "pain" receptors that give *only* C- or B-type impulses although statistically there is evidence for such a grouping. Encapsulated endings are rare and are so distributed as to make it seem very unlikely that they are specific and exclusive receptors for either of the two classes of stimuli. It is more probable that freely branching nerve endings are the principal receptors involved with both classes of stimuli, though it is futile to speculate at the present time concerning the physiological characteristics of the endings which determine the particular receptivities. One group of receptors may be regarded as responding primarily to stimuli of the sort which has been associated with epicritic sensibility, and the other group as responding primarily to stimuli of the traditional protopathic type.[4] The action potentials set up in the fibers connected with these receptors are usually different—slow and low potential changes generally being initiated in fibers from "protopathic" receptors with rapid and high potential changes generally being produced in fibers from "epicritic" receptors. (Cf. also 11.) At present there is no obvious histological basis for the separation of the two types of receptors, although fiber diameter may prove to be the determining factor. In view of the numerous failures to correlate sensory spots with special encapsulated endings in the human skin it is interesting to note that in the frog each of what appears to be two sensory "qualities" is, for the most part, determined by specific but probably histologically very similar free endings.

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[4] For a recent discussion of protopathic and epicritic sensibility see Stopford, (19*a*), also Adrian (2*a*).

SUMMARY

1. Recent literature presenting evidence for the existence of specific afferent nerve impulses is reviewed. A body of evidence exists indicating a general correlation of quantitative aspects of the action potential of afferent nerve fibers with specific sense modalities.
2. Using a Matthews amplifier and oscillograph in conjunction with a loud speaker, a camera, and a standing wave screen, observations of action potentials from single nerve fibers supplying receptors in the skin of the frog have been made. Some individual end organs were found which respond only to light touch; others were found which respond only to the class of stimuli known as painful in man. A few were found which respond to both types of stimulation.
3. The action potentials set up by touch are typically rapid and of larger amplitude. Those set up by "painful" stimuli are typically of longer duration and of smaller amplitude. Exceptions to both of these generalizations have been found.
4. Thermal stimuli applied to frog's skin must be very intense in order to initiate nerve impulses.
5. The frog may possess epicritic and protopathic sensibility. The two types of sensibilities found are markedly correlated with specific nerve impulses.

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LES IMPULSIONS AFFÉRENTES SPÉCIFIQUES ET LA SENSIBILITÉ CUTANÉE

(Résumé)

1. On analyse les études récentes qui montrent des témoignages de l'existence des impulsions afférentes spécifiques des nerfs. Il existe beaucoup de témoignages qui indiquent une corrélation générale des aspects quantitatifs de l'action potentielle des fibres afférentes des nerfs avec des modalités spécifiques des sens.

2. En employant un amplificateur Matthews et un oscillographe avec un haut parleur, un appareil photographique, et un écran vertical pour les ondes, on a fait des observations des potentiels de l'action des fibres seules des nerfs lesquelles donnent des récepteurs dans la peau de la grenouille. On a trouvé des organes individuels d'extrémité lesquels ne répondent qu'à un toucher léger; on en a trouvé d'autres qui répondent seulement à la classe de stimuli qu'on sait douloureux chez l'homme. On en a trouvé quelques-uns qui répondent aux deux types de stimulation.

3. Les potentiels de l'action causés par le toucher sont en type rapides et très grands. Ceux causés par les stimuli "douloureux" sont en type de plus longue durée et de plus petit potentiel. On a trouvé des exceptions à ces deux généralisations.

4. Les stimuli thermiques appliqués à la peau de la grenouille doivent être très intenses pour initier des impulsions des nerfs.

5. La grenouille peut posséder les sensibilités épicritique et protopathique. Les deux types de sensibilités qu'on a trouvés donnent une corrélation frappante avec les impulsions spécifiques des nerfs. HOAGLAND

SPEZIFISCHE AFFERENTE NERVENIMPULSE UND DIE KUTANE EMPFINDLICHKEIT

(Referat)

1. Es wird neue Literatur besprochen die auf das Bestehen von spezifischen Nervenimpulsen (afferent nerve impulses) hinweist. Es gibt Beweismaterial welches auf eine allgemeine Korrelation andeutet zwischen den quantitativen Aeusserungen des Kraftpotentials (action potential) afferenter Nervenfasern und spezifischen Sinnesmodalitäten.

2. Bei Gebrauch eines Mathewschen Vergrösserungsapparats (Matthews amplifier) und Oscillographes im Zusammenhang mit einem Schallvergrösserer (loud speaker) einem Photoapparat (camera) und einem stehenden Wellenschirm (wave screen) wurden Beobachtungen gemacht an den Kraftpotenzialen aus einzelnen Nervenfasern welche Rezeptoren in der Haut des Frosches versorgen. Es fanden sich gewisse Endorgane die nur auf leichte Berührung antworten. Andere, aber, antworteten nur auf Reize die der Mensch als peinlich anerkennt. Einzelne antworteten auf beide Reizarten.

3. Die durch die Berührung in Bewegung gesetzten Kraftpotenziale sind typisch rasch und von grossem Umfang. Die durch peinliche Reize ausgelösten sind typisch von längerer Dauer und kleinerem Potenzial. Es haben sich auch Ausnahmen dieser beiden Verallgemeinerungen gezeigt.

4. Thermalreize, die auf der Haut eines Frosches appliziert werden, müssen sehr stark sein, um Nervenimpulse auszulösen.

5. Es kann sein, dass dem Frosche sowohl epikritische wie protopathische Empfindlichkeit eigen ist. HOAGLAND

A STUDY OF MIRROR-WRITING IN RELATION TO HANDEDNESS AND PERCEPTUAL AND MOTOR HABITS*

From the Psychological Laboratory of Brown University

LEONARD CARMICHAEL AND HELEN CASHMAN[1]

I. INTRODUCTION

A study of the phenomenon of spontaneous mirror-writing offers important information in regard to the process of development of motor control and of perception in the human individual. An understanding of mirror-writing also yields valuable evidence in regard to the relationship between the function of the right and left hands. In the field of applied psychology a knowledge of the nature of mirror-writing is useful to the teacher of writing who must occasionally attempt to correct this disability. An insight into certain of the conditions which lead to this peculiar script is valuable to one who wishes to train the unskillful hand of an individual who has, through accident, lost the use of the previously preferred hand. The phenomenon is often considered a significant functional sign in the study of the pathology of the nervous system.

A number of summaries and criticisms of the literature of mirror-writing have been prepared. The most important of such reviews is that of J. K. Fuller (33), to which the present reader is referred for the early history of the problem. Subsequent to this paper is a brief and incomplete review by one of the present authors (21). More recently still is a review of the subject by Blom (9).[2]

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[1] The detailed study of the cases was carried out by H. Cashman. The present form of the problem was suggested, the tests selected, the literature reviewed, and the conclusions drawn by L. Carmichael.

[2] This summary purports to be a review of the German, English, and French literature on mirror-writting. It is to some extent inaccurate and incomplete, and is apparently quite largely based upon the work of Fuller (33). Among the references important for a knowledge of mirror-writing which are not included either by Blom or Fuller in their bibliographies are the following: Arps (1), Baldwin (3, pp. 95-99), Ballard (4, 5), Baudouin (7), Bennett (8), Bramwell (10, 11), Braun (12), Brinton (14), Brown (15), Bryan (16), Buchner (17), Caillé (19), Calhoun (20), Claiborne (22),

In this paper studies of seven typical cases of individuals showing spontaneous mirror-writing are reported. After the case histories are given, certain general conclusions in regard to the nature of the phenomenon, its development, and its importance for psychological theory are offered.

II. Case Studies

Case A. Girl 14 years 11 months old; Anglo-American parentage; IQ according to the Stanford Revision of the Binet-Simon test, 86; in eighth grade of school.

The subject was markedly left-handed. In the use of the dynamometer her best grip out of three trials with her left hand was 22.7 kgm., and her best grip out of three trials with her right hand was 11.4 kgm. In clasping the hands she placed the right thumb over the left. When a ball was thrown to her by the experimenter she caught it with the left hand. It was reported from her home that when both hands were needed, as in dressing, she uses her right hand to assist, and when one hand only is needed she uses her left hand. The use of Parson's manoptoscope[3] showed the subject to be consistently left-eyed.[4] The right side of the subject's body showed a slight paralysis which had been noticed since infancy.

The position of the body and arms in writing and drawing tests is shown in Figure 1. In the case of her normal writing, a sample of which is shown in the first and second lines of Figure 2,[5] she

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Dresch (28), Fildes (30), Fildes and Myers (31), Fränkel (32), Goldscheider (34), Herlihy and Baldwin (36), Ioteyko (38), Ireland (39), Jackson (40), Jones (41), Kerr (42), Kipiani (44), Leith (47), Lichtheim (48), Lochte (49), Lombroso (50), McHattie (51), Mettler (52), Peretti (58), Savage (61), Schaefer (62), Sherlock (63), Sollier (64), Soltman (65), Stier (69), Storck (70), Symns (72), Wallin (75), Weber (77), Wilson (78), Wolzendorff (79).

[3] The form of "manoptoscope" or "manuscope" used was that manufactured from B. S. Parson's directions by the C. H. Stoelting Company of Chicago. The manoptoscope was administered according to Parson's directions (57, pp. 78-87).

[4] The tests of handedness given above were selected because observation had shown them well suited to give a rough qualitative distinction between what is generally called "righthandedness" and "lefthandedness." Certain studies, including some unpublished work by the senior author and his students, indicate the fact that no single test of handedness is in all respects satisfactory, and that, indeed, a definition of handedness itself must probably ultimately be presented, not as an all-or-none phenomenon, but as a statistical conception. For the purposes of the present paper the questions and tests listed above were considered as adequate.

[5] The samples of drawing and writing reproduced in this paper are made from tracings that have been as accurately executed as possible.

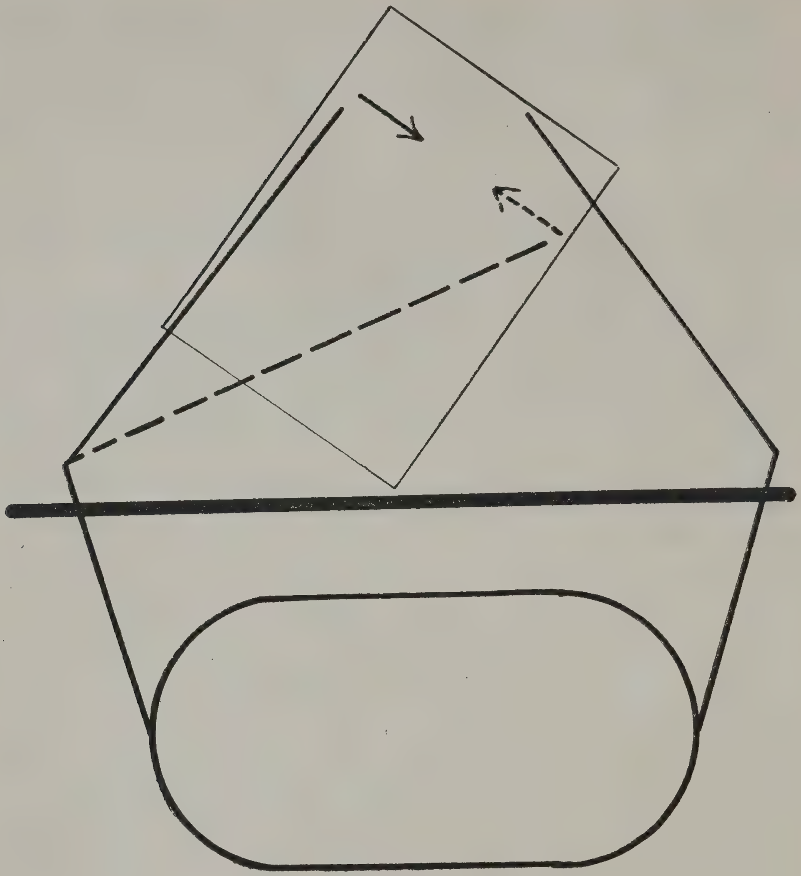
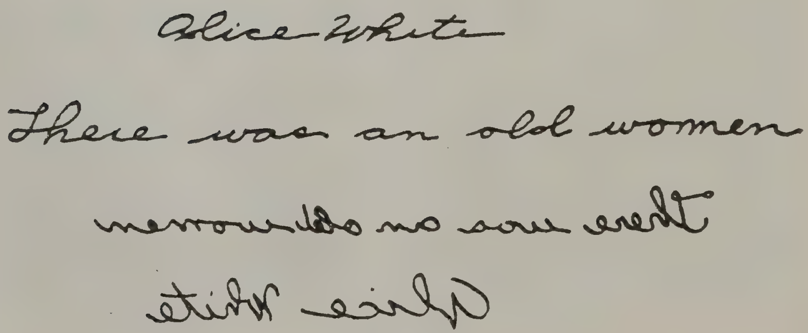


FIGURE 1



Alice White

There was an old women

There was an old women

Alice White

FIGURE 2

held her arms approximately as shown by the unbroken line of Figure 1. In mirror-writing, a sample of which is shown in lines 3 and 4 of Figure 2, she held her left arm as shown by the broken line in Figure 1. She also assumed this posture when copying the picture of the animal shown in Figure 3. The subject's drawing is not reproduced, but in it the head pointed in the same way as shown in the model drawing. When making a drawing of a railroad train *from memory,* however, the sketch shown in Figure 4 was reproduced. It will be noted that the train is headed toward the left hand.

A history of the case shows that the subject's first writing was in true mirror-script. She remembers great difficulty in learning to write in a manner that was satisfactory to her teacher. Records show that she was finally corrected in the second grade. Now, in the eighth grade of school, she never reverts to mirror-writing except for her own amusement.

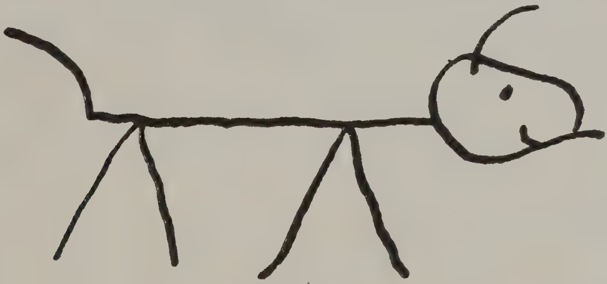


FIGURE 3

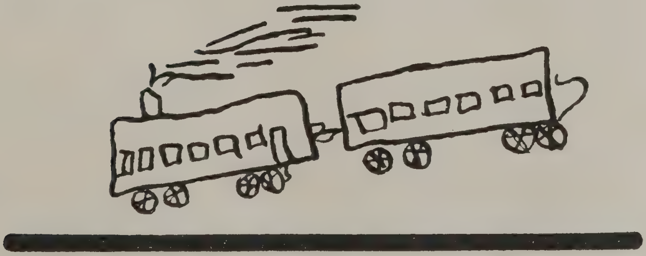


FIGURE 4

On first examination it took her 1 min. 14 sec. to write the nursery rhyme,

> "There was an old woman
> Who lived in a shoe,
> She had so many children
> She didn't know what to do."

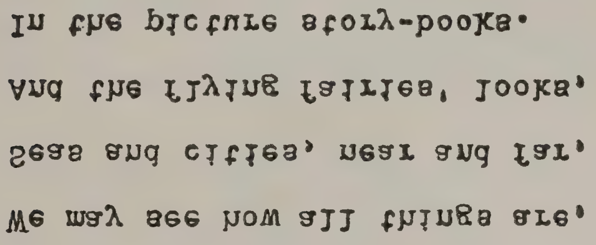
in normal script with the left hand when the copy was before her. It took her 1 min. 37 sec. to write the same rhyme in mirror-script with the left hand with the copy still before her. According to the Ayres scale for measuring handwriting, the quality of the subject's normal and mirror-script might both be rated as about 50 (2). It is possible to say, on the basis of the study of more extended samples than those given in the illustration, that her normal writing showed slightly greater "ease," while her mirror-script showed greater uniformity. The possibility of practice or inhibitory effect in first writing the rhyme in normal and later in mirror-script was guarded against in this and in the following cases by having a second test made after the lapse of one month. At the second test the subject was asked to write the same nursery rhyme first mirrorwise, then normally. This time it took her 1 min. 46 sec. mirrorwise, and 1 min. 22 sec. for normal writing. The difference in time required for writing the sample mirrorwise and normally was therefore 23 sec. and 24 sec., respectively. As in the previous test the qualities of writing were rated as approximately equal.

The subject wrote her name in mirror-script in 18 sec. and normally in 17 sec. The subject was then asked to read the mirror-typewritten poem shown in Figure 5 and the normally typewritten poem shown in Figure 6. She read both at the same rate of speed, 11 sec., and made one mistake in each. She also read mirror-script (not her own, see Figure 7) and normal script (not her own) with equal ease.

Case B. Boy 11 years 8 months old; IQ according to the Stanford Revision of the Binet-Simon test, 65; in the third grade of school.

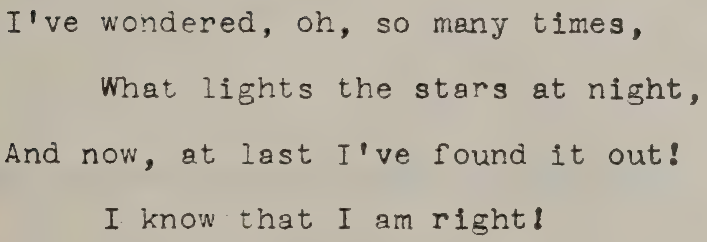
In the use of the dynamometer his best grip out of three was 22.7 kgm. with the left hand and 19.1 kgm. with the right hand. His score on a pencil and paper tapping test was 62 using the right hand, and 57 using the left hand. When clasping the hands he placed the right thumb over the left. When a ball was thrown to him by the experimenter he caught it with the left hand. Use of the Stoelting form of Parson's manoptoscope showed the subject to be right-eyed. In the cube test of the Binet scale when told to arrange five cubes according to weight and to put the heaviest at the left and the lightest at the right, the subject reversed the order in two out of three trials. During various examinations, so far as determined, he always used the left hand in preference to the right when but one hand was needed.

The position of the body and arms in writing normal script is



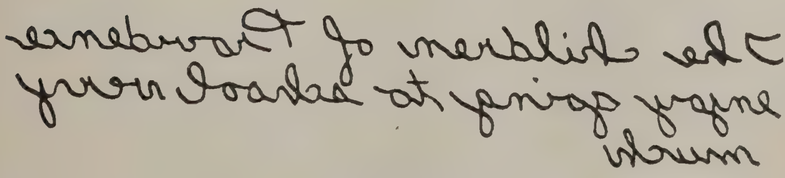
In the picture story-books.
And the flying fairies' looks,
Seas and cities, near and far,
We may see how all things are,

FIGURE 5



I've wondered, oh, so many times,
What lights the stars at night,
And now, at last I've found it out!
I know that I am right!

FIGURE 6



The children of Providence
enjoy going to school very
much

FIGURE 7

shown in Figure 8, that assumed when writing mirror-script is shown in Figure 9. When asked to draw a copy of the animal shown in Figure 3 he used his left hand, spontaneously beginning on the right and working toward the left. When asked to use the right hand in drawing the same figure he began at the left and worked toward the right. The position of the paper in the first case of drawing was approximately that shown in Figure 9, while the position in the second instance was that shown in Figure 8.

When the subject was first taught to write, he developed spontaneous left-handed mirror-script, and showed himself unable to write in any other manner. He had such difficulty in learning to write normally that the teacher suggested using the right hand. As soon as he changed hands he began to learn normal writing quite

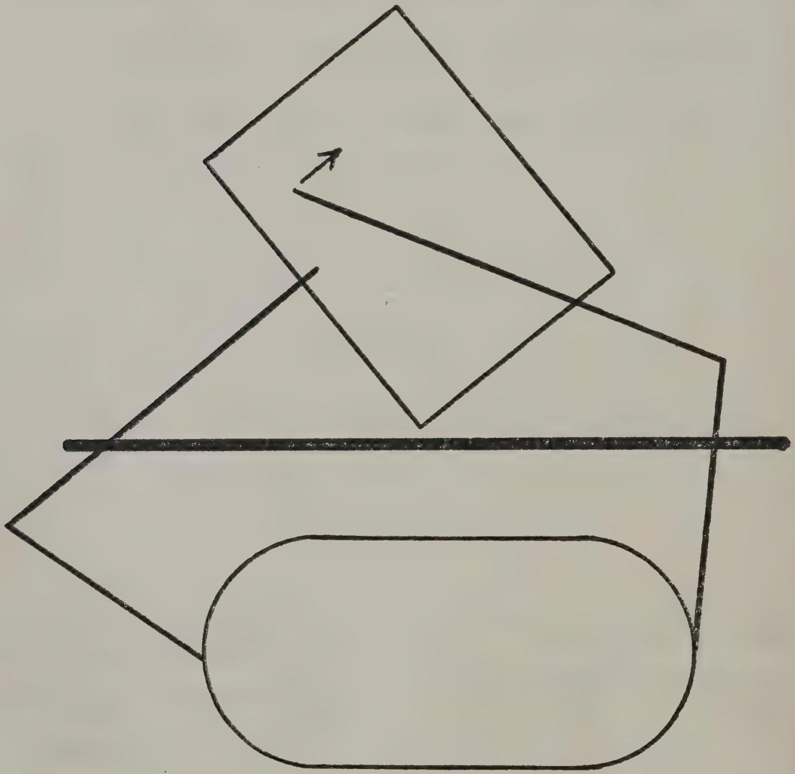


FIGURE 8.

readily. Since learning normal writing he says that he has never reverted to mirror-writing until asked to do so by the experimenter. It should be noted that the boy at the time of examination showed pronounced stuttering. In Figure 10 are shown samples of the subject's writing in normal and in mirror-script.

On first examination it took the subject 2 min. 47 sec. to copy the nursery rhyme used in Case A ("There was an old woman, etc.") in normal script with the right hand, and 2 min. 35 sec. to copy the same poem in mirror-script. According to the Ayres scale, his normal writing might be rated as about 40 and his mirror-writing as about 30. It may be noted also that the first copy of the animal, made with the left hand from choice, was inferior to the copy of the animal made at the experimenter's suggestion with the right hand. These drawings are not reproduced here. When, after the passage

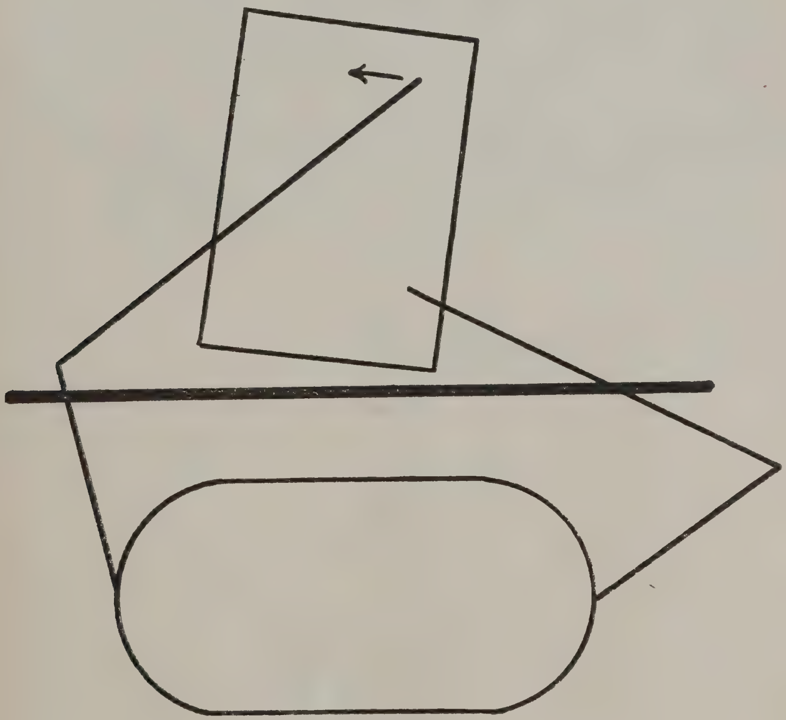


FIGURE 9

of one month, the subject was again asked to copy the rhyme, this time using mirror-script first and normal script second, he took 3 min. 28 sec. with mirror-script and 2 min. 26 sec. in normal script. The quality of both types of writing was much the same as that shown in the previous month.

The subject wrote his name with left-handed mirror-writing in 16 sec. and right-handed in normal writing in 17 sec. The subject is such a poor reader that it was very difficult to test his ability to read either normal or reversed typewriting or script. He showed himself able to read "See the man" in typewritten mirror-script in

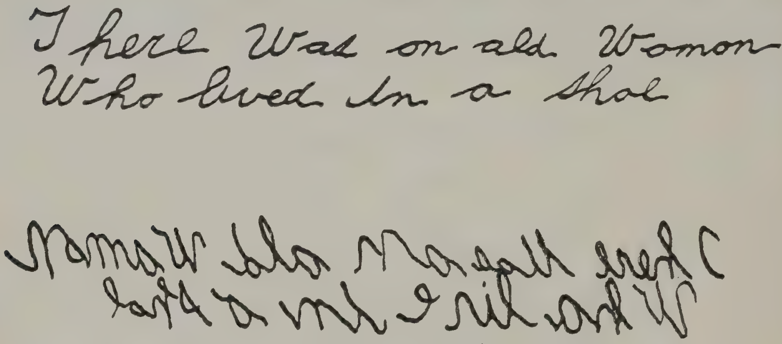

There Was on ald Womon
Who lived In a shol

FIGURE 10

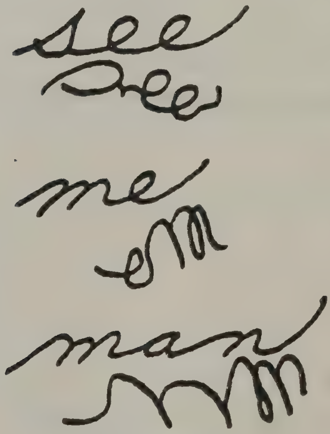


FIGURE 11

2½ sec., and "It is a cat" in normal writing in 2 sec.

Case C. Boy 9 years old; colored; IQ according to the Stanford Revision of the Binet-Simon test, 75; in grade 1B in school.

In the use of the dynamometer his best grip out of three with the left hand was 18.6 kgm. and his best grip out of three with the right hand was also 18.6 kgm. In clasping the hands he placed the right thumb over the left. When told to catch with one hand a ball thrown to him by the experimenter, he caught it with the left hand. He uses his left hand for everything that can be done with one hand, and uses his right hand only to assist the left when two hands are needed for the task in question. Using the Stoelting form of Parson's manoptoscope, the subject reported seeing a "7" which, no doubt, was the "L."

The position of the body and arms in writing and drawing was in all cases similar to that shown in Figure 9. It did not prove possible to make him either write or draw with the right hand.

The subject's distinctly inferior general intellectual equipment and age made it difficult to test him upon such tests of reading and writing as those used in the cases reported above. He could read and write only a few of the very simplest words. For all writing, as noted above, he uses the left hand, and begins at the right of the paper, working toward the left. This procedure in his case always gives mirror-script. In copying 1 — 1 = 0, he wrote 0 = 1 — 1. When he copies designs and pictures he reverses them. He insists upon saluting the flag with his left hand. Figure 11 shows his attempt at copying "see me" and "man" from the letter models actually given. It is interesting to notice that the word "see" was copied correctly, but his teacher reports that great practice had been

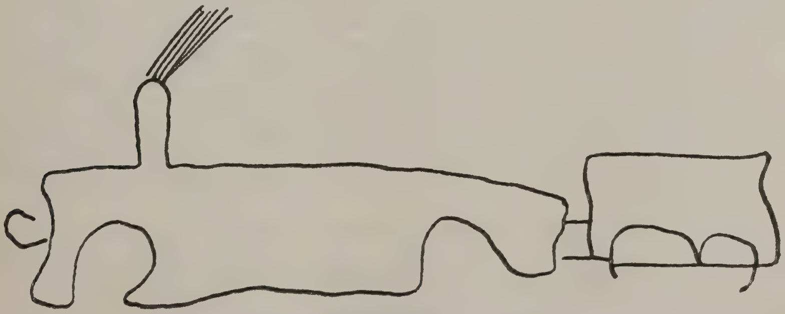


FIGURE 12

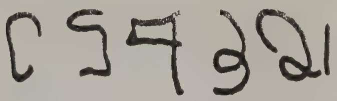


FIGURE 13

given to this word. The train shown in Figure 12 was drawn with the left hand, beginning at the right of the paper and working toward the left. The numbers 1 2 3 4 5 6 as written by the subject from dictation are shown in Figure 13.

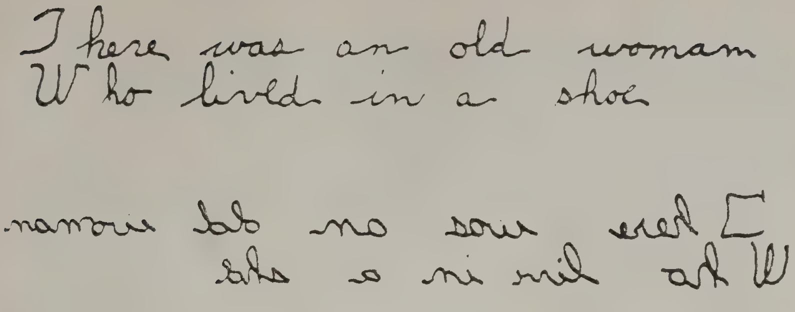
Case D. Girl 11 years old; IQ according to the Stanford Revision of the Binet-Simon test, 87; in the fourth grade of school.

In the use of the dynamometer her best grip out of three trials with her left hand was 18.6 kgm., and with her right hand was 24.55 kgm. In clasping the hands she placed the right thumb over the left. When a ball was thrown to her by the experimenter she caught it with her left hand. It was reported that at home she uses her left hand always when one hand is needed, and uses her right hand only when the two hands are needed for some special task. The use of the Stoelting form of Parson's manoptoscope showed the subject to be left-eyed.

In all her writing and drawing the subject used her left hand. Figure 9 shows the approximate position of the body and arms in this work. In drawing the animal (Figure 3) she drew it facing the right hand.

This girl, as far as known, has always used her left hand in preference to the right in skilled tasks. She had great difficulty in learning to write. In writing she used her left hand, began at the right of the page and wrote mirrorwise. The teacher had her trace sandpaper letters until she could write normal script. It took about six months to correct her and this was with constant vigilance and special help. She now writes normal script fairly well, but still uses her left hand. Occasionally in writing figures like "3" she reverts to mirror-script. She was a good reader when tested, but at first, it is reported, she had great difficulty in learning to read. Figure 14 shows samples of the normal and mirror-writing of the subject.

On first examination it took the subject 2 min. 14 sec. to write the nursery rhyme "There was an old woman, etc." in normal writing and 3 min. 14 sec. mirrorwise. According to the Ayres scale the quality of both the subject's normal and mirror-script is approxi-



There was an old womam
Who lived in a shoe

FIGURE 14

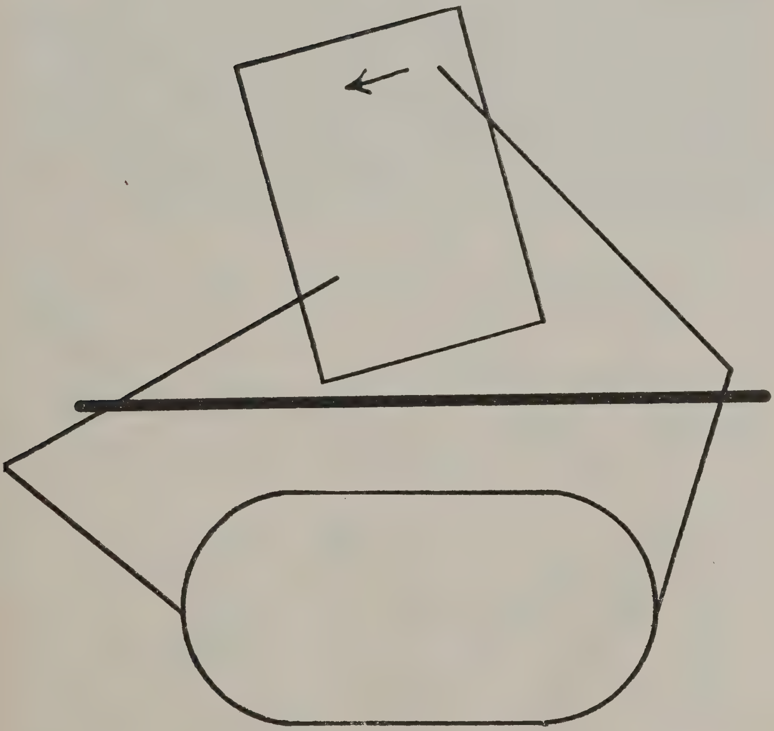


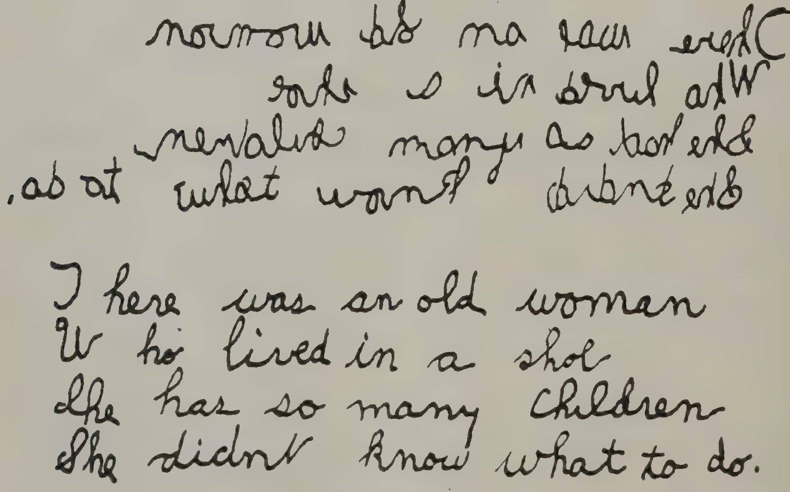
FIGURE 15

mately 60. In her second attempt to copy the rhyme, after the passage of one month, this time using mirror-script first and normal script second, she took 3 min. 28 sec. with mirror-script and 2 min. with normal script. The quality of the second attempt was about the same as that of the first.

The subject wrote her own name in normal writing in 18 sec. and in mirror-script in 31 sec. When asked to read the mirror-typed poem shown in Figure 5 she took 2 min. 27 sec. and made nine mistakes. She read the normally typed poem (Figure 6) in 16 sec. and made no errors. She could only read "in," "are," "of," and "from" in the mirror-script passage shown in Figure 7, but she read without error in a similar passage in normal script.

Case E. Boy 7 years 6 months old; IQ according to the Stanford Revision of the Binet-Simon test, 103; in the second grade.

In the use of the dynamometer the subject's best grip out of three trials with the left hand was 14.1 kgm. and his best grip out of three with the right hand was 22.3 kgm. In clasping the hands he placed the right thumb over the left. When asked to catch a ball with one hand he caught it with the right hand. In the tapping test the subject scored 36 with the right hand, while with the left hand the marks were so inaccurately made that it was impossible to count them, though there were considerably fewer of them than with the



T here was an old woman
W ho lived in a shoe
She has so many Children
She didnt know what to do.

FIGURE 16

right hand. The use of the Stoelting form of Parson's manoptoscope showed the subject to be right-eyed. It is reported that the subject uses his right hand from preference at home for throwing, catching, eating, and in all operations involving the preference of one hand to the other. He also uses his right hand for all writing and drawing.

The position that the body and arms assumed was approximately that shown in Figure 15. Figure 16 shows samples of his normal and mirror-writing.

The subject has never shown any tendency to use his left hand from preference in any skilled act. Since beginning to write he has used his right hand exclusively, but with this hand he has always produced mirror-script. He begins to write at the right side of the page and works toward the left. The anomaly of his writing puzzled his teachers and it was only by chance that one of the teachers discovered that by turning his paper over and holding it up to the light she could read it. The boy now writes normally with his right hand as the result of much correction and training. He is in general making poor progress in school and is still having great difficulty in learning to read. His linguistic habits seem retarded. His diction is still in certain respects characteristic of early childhood.

On first examination it took the subject 6 min. 10 sec. to copy the nursery rhyme "There was an old woman, etc." with his right hand in normal script. With the same hand he copied the same rhyme in mirror-script in 6 min. 27 sec. According to the Ayres scale the quality of his normal writing is approximately 50 and that of his mirror-writing approximately 40. When asked to copy the animal (Figure 3) he began at the left and worked toward the right. In drawing the train from memory he first drew a passenger car and then drew an engine at the right of it, as shown in Figure 17. In the second test, at the end of the month, it took the subject 6 min. 12 sec. to copy the same nursery rhyme mirrorwise and 4 min. 57 sec. to copy it in normal script, performing the tasks in this order. The quality of his normal script in the second trial was somewhat better than on the previous test, and the task was performed in a shorter time. The mirror-script was not consistent in this trial, two whole words being written in normal script.

The subject wrote his name in mirror-script in 53 sec., but normally in 31 sec.. He read the mirror-typed sentence, "See the man," in 3 sec. He read the normally typed sentence, "It is a cat," in 3 sec. "I see a big dog" and "The ball is round" were written in mirror-script. He read the first as "I see a girl dog" and the second as "The doll is . . . " He could make nothing of the word "round." He read without error both of these sentences when written normally.

Because of the importance of this case of a right-handed mirror-writer, it has been studied on several subsequent occasions which have resulted in confirming the findings recorded above. When asked to copy a spear head, the boy drew it by lines, some of which were drawn from right to left and some from left to right.

Case F. Girl 10 years 1 month old; IQ according to the Stanford Revision of the Binet-Simon test, 83; in grade 2A.

In the use of the dynamometer her best grip out of three trials with her left hand was 17.7 kgm., and her best out of three with her right hand was 15.9 kgm. In clasping the hands she placed the right thumb over the left. She caught the ball thrown to her by the experimenter with the left hand. She uses her left hand for writ-

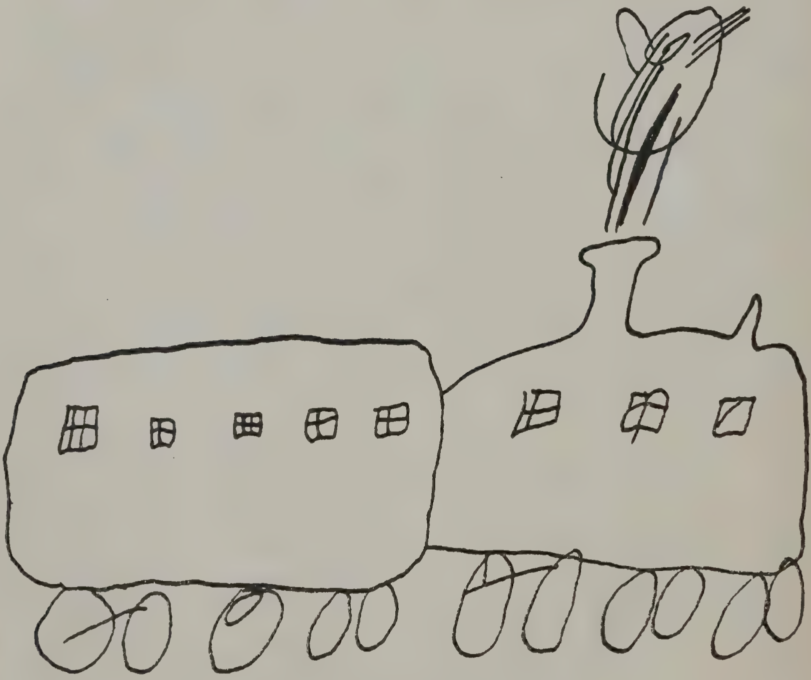
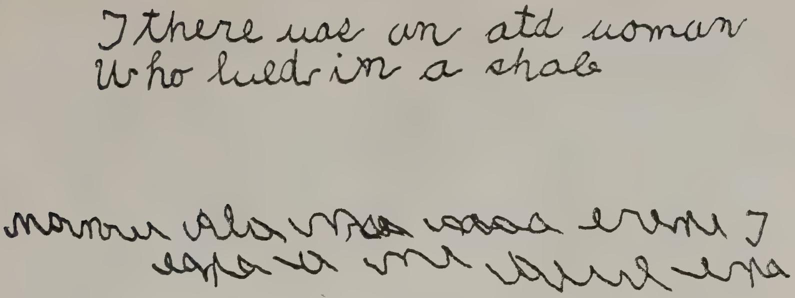


FIGURE 17



I there uas an atd uoman
Who lued in a shoe

FIGURE 18

ing, sewing, drawing, and all other handwork in school. Use of the Stoelting form of Pearson's manoptoscope showed the subject to be right-eyed.

The position of the body and arms in writing and drawing tests was that shown in Figure 1, the broken line showing the position in mirror-writing. In drawing the animal she used her left hand, began at the right of the paper, and worked toward the left. She refused to try to draw a picture of a train from memory.

A history of this case shows that when she first began to write the subject spontaneously produced mirror-script, which became eventually fairly well established. At length an effort was made to change this script to normal writing. The endeavor was accomplished fairly rapidly, but the subject is still a poor writer. In reading she makes a great many reversals of the typical *was* to *saw* type, spells *of* as *fo,* and makes similar mistakes in many other words. The subject now never reverts to mirror-writing, but when asked by the experimenter to see if she could do so successfully she showed that she had not lost this ability. Her speech shows slight traces of a lisp. Samples of her mirror- and normal writing are shown in Figure 18.

On first examination it took the subject 4 min. 43½ sec. to copy the nursery rhyme, "There was an old woman, etc." in normal script, and it took her 4 min. 55 sec. to copy the same rhyme in mirror-script. She used the left hand in both cases. According to the Ayres scale the quality of her writing in both cases might be rated as approximately 20. In her second attempt to copy the rhyme, after the passage of one month, in which test she used mirror-script first and then normal writing, it took the subject 6 min. 39 sec. to copy the rhyme in mirror-script and 4 min. 39 sec. to copy it in normal writing.

The subject wrote her name in mirror-script in 21 sec. and in normal script in 19 sec. It took her 28 sec. to read "See the man" typed mirrorwise, and in doing so, she read *the* as *hat*. It took her 3 sec. to read "It is a cat" typed normally. She read "I see a big dog" written mirrorwise, and "I see a girl go" each in 12 sec. She read "The ball is round" written normally in 5 sec.

Case G. Girl 11 years old; IQ according to the Stanford Revision of the Binet-Simon test, 94; in an ungraded room in school.

In the use of the dynamometer the subject's best grip out of three trials was 18.1 kgm. for each hand. In clasping the hands she placed the right thumb over the left. She caught the ball thrown to her by the experimenter with the left hand. She is reported in

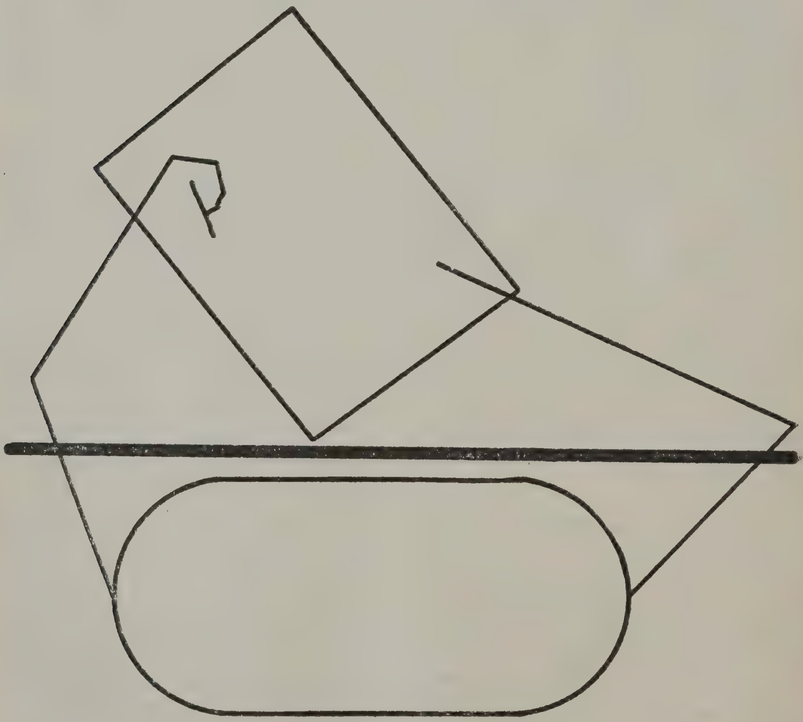


FIGURE 19

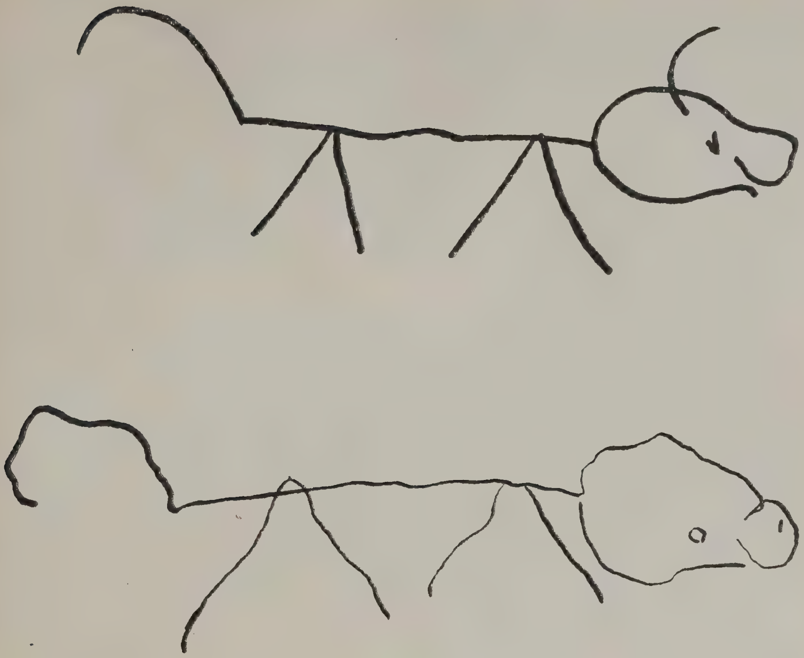


FIGURE 20

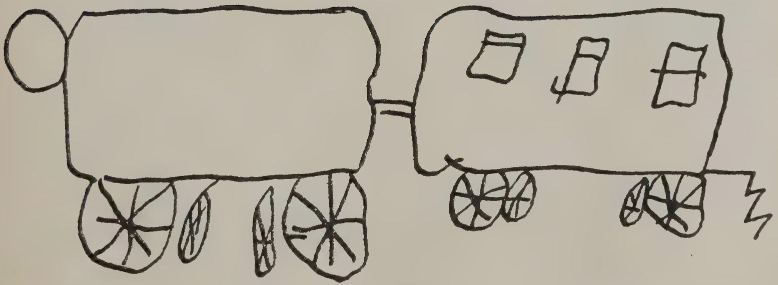


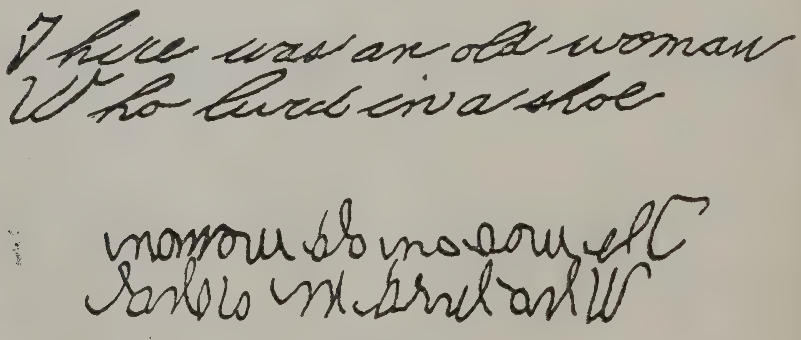
FIGURE 21

school and home to be extremely left-handed. Use of the Stoelting form of Parson's manoptoscope showed her to be left-eyed.

The position of the body and arms in writing when using the left hand is shown in Figure 19. In drawing the animal with the left hand the subject started at the right and worked toward the left. Working with the right hand also, she started at the right and worked toward the left, but with much less power and control, as shown by the weaker lines of the lower drawing of Figure 20 (upper drawing by left hand; lower by right). Her drawing of the railroad train is shown in Figure 21.

At the time of the study the girl's present teacher knew nothing concerning the fact that the girl had been at one time a mirror-writer. The child now writes and draws with her left hand. She had become unaccustomed to writing mirror-script, but did revert to it when told to do so, though now she said that it was harder than it had been in the past. Samples of her normal and mirror-script are given in Figure 22.

On first examination it took the subject 2 min. 22 sec. to copy the nursery rhyme, "There was an old woman," in normal script, while it took her 2 min. 55 sec. to copy the same rhyme in mirror-script. According to the Ayres scale the subject's normal writing might be rated as approximately 60, and her mirror-script as approximately 50. In her second attempt to copy the rhyme, after the passage of one month, it took her 3 min. 28 sec. to copy the rhyme mirrorwise, and 2 min. 14 sec. to copy it in normal script. The quality of the two types of writing was practically the same as on the previous trial.



There was an old woman
Who lived in a shoe

FIGURE 22

The subject wrote her name normally in 16 sec. and in mirror-script in 32 sec. She read a normally typewritten verse with no errors, but had great difficulty in reading the mirror-verse shown in Figure 5. It took her 2 min. to read this passage. Reading it, she made seven mistakes.

III. General Statements in Regard to the Above Cases

In summary of the cases presented above the following statements may be made:

1. All showed a mirror-writing in what may be characterized as a rather marked degree.
2. Mirror-writing, so far as could be determined, originated spontaneously in each subject. That is, there was no evidence that any of the individuals tested had received direct instruction in mirror-script or had copied from models written in mirror-script.
3. In all cases there was a variation between the time required for mirror-script and the time required to write normal script as judged by tests in which the practice effect of the test was to some extent counteracted by allowing one month to elapse between tests.
4. In a number of cases there was a difference in quality between mirror-writing and the normal script of the same subjects.[6]
5. Subjects who could write mirror-script differed markedly in their ability to read: (*a*) normal script, (*b*) normal typewriting, (*c*) their own mirror-script, (*d*) mirror-script, (*e*) mirror-typewriting.
6. In drawing most of the subjects showed some peculiarity of either or both of the following:
    a. Movement of the body, arms, and hands during the process of drawing, or
    b. The facing of the object drawn in a manner said to be characteristic of a left-handed rather than of a right-handed individual.[7]

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[6] When the results in speed and quality favor normal script, it should be noted that insistent school training and practice is in each case given to the normal script, whereas everything is done to discourage the production of mirror-script.

[7] It should be noted that the two tests of the way in which drawings were spontaneously faced were essentially different. In the first test a drawing (Figure 3) was presented to the subject and he was allowed to copy it while looking at the model. Typical differences between right- and left-handed drawings appeared but no head-tail reversals. In the second test the subject was asked to draw from memory a railroad train. In all in-

7. The position of the two arms and the manner of holding the pencil in the various cases noted tends to be quite different from case to case, and no bodily position characteristic of all mirror-writers may therefore be described.

8. All cases noted with the important exception of Case E were left-handed[8]

9. No generalization can readily be made in regard to the so-called intelligence or personality of the cases studied.

10. No generalization can be made in regard to the reading ability or speech habits of the cases studied.

IV. Theoretical Conclusions

A classification of previous theories of mirror-writing, very slightly modified from that presented by J. K. Fuller (33, pp. 214 f.), may be given as follows:

1. Explanations which depend in some way upon the facility of external motions of the limbs.

2. Those which place the emphasis upon the facility of centrifugal motions of the limbs, but in addition attribute the ultimate causation of specific movements to bilateral representation on the cerebral cortices.

3. Those hypotheses based primarily upon bilateral representation on the two cerebral hemispheres. This group is closely allied to group 2.

4. Those that admit a single specialized writing-center in which a disorder may take place.

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stances of left-handed mirror-writers some indications were observed of reversal, but the train was not always headed in the way that is said to be typical of the left-handed draftsman. The drawing of the train made by Case E, the right-handed mirror-writer, showed strange factors as noted in the report of the case. Unpublished studies indicate, however, that the facing of a drawing is not always associated with handedness. For a discussion of this problem and for the source of the present tests cf. Dearborn (25, pp. 185 ff.).

[8] The views of previous writers in regard to right-handed mirror-script are confusing. It has been noted under a peculiar condition of hypnosis (Peretti, 58, pp. 480 ff.). "Right-handed mirror-writing is a purely unnatural and artificial form of chirography," says Rudolf (59). Kingman (43) gives a number of observations on right-handed mirror-writing in normal individuals who were unaware of the ability or who used it as children in writing code letters. A similar report is made by Fuller (33, pp. 215 ff.). The case reported in this paper is the most certain case of spontaneous right-handed mirror-writing to which the writers have found reference.

5. Those that depend upon disturbance of vision, or of the visual centers.

6. Those which recognize various controlling factors for individual voluntary reversals. Thus the movements may depend upon a difficulty of attention or of motor, visual, mental, auditory-motor, or some other form of imagery.

Fuller himself shows that the hypnotic trance and the influence of drugs assist in making the normal individual able to write mirror-script, the latent ability for such writing being present in many individuals. He assumes that mirror-writing depends upon two conditions: (*a*) that there is a single grapho-motor center of the cortex for written symbols that is employed for right-hand writing and that the identical sensory-motor relation is employed in left-handed reversed writings; and (*b*) that the "psychological governor," which supervises our ordinary writing, must be so arranged or altered that the physiological provision for mirror-writing is given an opportunity to act (33).

On the basis of the present study the writers feel that the theories summarized above are not adequate to all of the facts and are unnecessarily complicated. Fundamentally, the shortcoming of most previous theories seems to be that the process of mirror-writing is considered, not genetically, that is, in the case of writing as a result of learning, but as a unified single phenomenon always at the stage characteristic of the complete act. The cases recorded above show that the phenomenon of mirror-writing varies from case to case. In some it is better developed than in others. In some it is performed with the hand in one position, in others the hand is differently employed to produce the script. Some read mirror-printing and mirror-writing with ease, and some cannot read it at all. In fact, every observation upon the phenomenon points to the fact that it is a complex motor performance that has developed as a result of many apparently chance factors which were determinants in the learning process of the individual under consideration. The important period in this development is the so-called *scribble period.* It is in this significant period in learning to write that the so-called trial-and-error process occurs. In nearly all children, but particularly in left-handed children, some mirror-reversals may usually be observed as one comes to the part of this period when recognizable form begins to appear in the developing script (31, 35). In this period the individual gradually acquires the subtle eye-hand coordinations which eventually make it possible for him to copy a sample of writing.

To the adult observer it seems almost incomprehensible that a model written in normal script can be copied in mirror-script by a child who is learning to write. The cases given above, however, demonstrate the fact that this is exactly what does occur. Of the cases cited above not one, so far as could be discovered, had received any special training in mirror-script.[9] In each individual mirror-writing had been learned "spontaneously" from copies in normal script. In learning mirror-script, it must be noted, the copy is, in a certain sense, followed. Indeed, the way it is followed throws some light upon so-called "learning by imitation." Thus the American school child learns mirror-writing that is similar to the copies that are given him. The German school child learns mirror-German-script that is similar to the copy that is given him. But this is not a process due to a faculty of "imitation" but to the fact that in a process of trial-error-and-accidental success the correct responses are gradually built up.[10] In the opinion of the present writers, therefore, the process of integration which makes possible the writing of normal as well as of mirror-script can only be understood in terms of the so-called trial-and-error aspects of the learning process.[11] The relevant aspects of this developmental process involve both the genetic development of visual and kinaesthetic perception of form and the independent growth of skill in hand movements resulting from neural activities which were initiated by the stimulation of various receptors. Too much theorizing in regard to mirror-writing has been carried on by those who are accustomed to think of perception and eye-hand coordination, particularly in so-called "voluntary" movements, as always fixed in the infant and child at an adult level. There is little doubt that the perception of script by the child who has not yet learned to write is very different from the perception of script by the child who has learned to write. The child who is just beginning to read and write may well respond to a sample of writing in a way that is radically different from the response to such script by a normal literate child or adult. As W. Stern has said, "The child's unconcern as to whether his drawings correspond with the objects drawn is also shown in the remarkable 'misplacements' which occur fairly often in the very early stages. Above and below, vertical and horizontal, right and left, are interchanged without the child either noticing or being disturbed by it. . . . We find here all possible misplacements; the tilting over at an angle of 90°, the position upside down, the reflected image."[12] Or, as M. W. Curti well says in summary or her experiments upon the change in the visual and perceptual field by the use of prismatic glasses, "To the adult, nothing seems so fixed in the nature of things as objective space, as 'up,' 'down,' and 'square.' These experiments indicate, however, that such perceptions depend on our specific human experience with things in reacting to them. 'Up' means where our arms are, 'down,' near our feet, and so on. The experiments have demonstrated the possibility of a gradual trial-and-error acquisition of space perceptions in children."[13]

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[9] In the whole literature of the subject that has been reviewed for the present paper there is only one instance of schoolroom instruction in mirror-writing. A teacher in a small school in Bermuda hurt her right hand. She found that she could write mirror-wise with the left hand. She gave this copy and mirrors to the children of her class. After a little while three children were found to be able to write good mirror-writing. Cf. Kingman (43).

[10] For speculation in regard to the tendencies to mirror-writing determined by various forms of script (Chinese, Manchu, Early Greek, Etruscan, etc.), cf. Clapham (23).

[11] The term "trial-and-error" is used here merely as a "shorthand expression" for the fact that varied responses in a persisting situation are made because of the condition of the individual and the stimulus situation, and that subsequently the less successful acts are eliminated and the more successful acts learned. [Cf. Warren and Carmichael (76, pp. 188 ff.).] The terms "trial," "error," and "success" need not imply "purpose" on the part of the subject, as they are merely convenient terms used by the experimenter or observer. From this point of view the conception of trial and error is not open to the criticisms of Kuo (46).

In the opinion of the present writers, there seems to be good reason to believe that the phenomenon of mirror-writing is to be best understood by keeping clearly in view the process by means of which both perception and the motor activities of writing develop in the individual. It seems, therefore, that mirror-writing itself may be an essentially normal process, or at least a process involving no special pathology of the organism.[14] Mirror-writers integrate a script that is often essentially like the copy given them, save that it differs in being the reflected image of the copy. Cases are noted above in which a subject's own mirror-writing and unfamiliar mirror-writing as well as mirror-typewriting were read with ease almost equal to that of normal writing and typewriting by children who in everyday life use only normal writing and read normal printing. This ability to read mirror-script, however, is apparently not universally correlated with the ability spontaneously to write mirror-script, as might be expected if the whole process is an integration dependent upon trial, error, and the fixation of adaptive responses.[15]

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[12] Stern (68, pp. 371-372). Reference should also be made to Stern (66), and, for special reference to mirror-script, to Stern (67) and to Krötsch (45).

[13] Curti (24, p. 222). See also Wooster (80). In this connection the following experimental studies should also be consulted: Stratton (71), Ewert (29).

[14] Many writers have held that mirror-writing is normal in the left-handed. Cf. Mills (53), Vogt (74), Ballet (6). Many others note that

If the view presented above is correct, it seems that the phenomenon of mirror-writing is to be considered as an unusual motor and perceptual integration which develops normally in certain children who are for the most part, but not always, markedly left-handed. It seems, moreover, that the earlier theories proposed to account for this phenomenon are in reality not contradictory. They are rather to be understood as emphasizing some partial aspect of the physiological or psychological process which underlies normal learning, such as receptor activity, motor response, or the activity of special parts of the central nervous system. Each of these functions is to be understood, it seems to the present writers, only in terms of the activity of the whole receptor-neuro-motor processes of learning which have brought about the development of the mirror-writing skill. The large number of theories that have explained the phenomenon in terms of "attention," "imagery," "sensation," or "the psychological governor" need not be considered here. Such theories are only as adequate or as inadequate to explain mirror-writing as they are to explain any normal learning or normal motor function. The present writers reject these theories and the terms in which they are written, because they believe that learning can be described in a more satisfactory and simple manner. Similarly, so far as the view that mirror-writing is dependent upon some special "center" in the brain is concerned, there can be no doubt of the

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some trace of mirror-reversal is found in most left-handed children. The point that is being made in this paper is that under certain conditions, as shown in Case E, it may be developed by a process of learning even in the right-handed child.

[15] Gordon (35, p. 336) states in regard to mirror-writers that the majority were unable to read what they had written. It should be emphasized that many mirror-writers, however, can read their own and novel mirror-writing and mirror-typewriting.

truth that "centers" in the cortex are important in mirror-writing. Many neurologists allege that knowledge of the phenomenon of mirror-writing and of the conditions of its development in the individual are of some importance in understanding cerebral physiology. Save in the most general sense, however, it seems that knowledge in regard to the special brain localization which is said to underlie mirror-writing is still too hypothetical to be taken by the psychologist as explanatory of the facts in regard to the nature and development of mirror-writing which he has observed. A brief statement in regard to one such theory may, however, not be out of place at this point. An interesting recent theory of the cerebral mechanism of reading and writing with particular reference to reversal is that of Orton.[16] He reviews the evidence tending to show that the relevant parts of the cortex involved in visual function may be classed as visual-perceptive, visual-recognitive, and visual-associative. He then explains the phenomena of disability in reading and mirror-writing in terms of interference in the dominance relationships of these areas in the two hemispheres at the visual-associative level. But, as Orton himself points out in a quotation from Marie in the comparable case of so-called "langauge centers," there is no evidence that they are preformed, but rather that they are adapted to the language function by training. It seems, therefore, to the present writers, that whatever the final conclusions in regard to the cerebral mechanics of mirror-writing may be, there can be no doubt that a study of the nature of the phenomenon and its development at the psychological level is important. Whatever findings in regard to behavior are thus disclosed must, if they are valid observations, be true, whatever brain conditions are later found to subtend them. There can be little doubt, however, that a knowledge of all the psychological peculiarities of writing, reading, and speech, as well as a knowledge of the preferred eye, hand, and foot will be found to be significant in relation to anatomical facts when a definitive neurological account of the nature of the "dominance" of one hemisphere over the other is written. At present, however, detailed brain physiology is no more essential to a *psychological* account of mirror-writing, valuable as the neurological facts would be if they could be secured, than is detailed neurological knowledge essential to a modern psychological quantitative and experimental description of the conditions of normal learning.[17]

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[16] Orton (55, 56). For a psychological theory which suggests the relationship between difficulties in reading mirror-writing, cf. Dearborn (27, pp. 205, 50-75), also (26).

It is not without significance that throughout the literature of mirror-writing the phenomenon has been considered as an unfavorable clinical sign.[18] This may be due to the fact that while mirror-writing is an integration which can quite readily and normally be developed in a child as he learns to write, particularly if the child is markedly left-handed, it is after all a series of responses that will be eliminated by the same process of selection save under exceptional circumstances. The fact that there is a bilateral symmetry of movement should not, of course, be forgotten. As Peretti and many other writers point out, as a child learns any movement the symmetrical limb is also brought into play (58, p. 478). It may well be that the left-handed child who is taught to use the right hand in early writing practice will thus, when he does find it expedient to use the left hand, already have certain habit sequences established which will make for the rapid integration of the left-handed mirror-script.[19] Such writing is not a completely "successful act" in the meaning of that phrase as it is usually used in description of the process of so-called trial-and-error learning. The individual of less than normal ability in this, as in all other respects, may be slower in correcting any not quite adequate responses than is the normal or superior individual. This to the present writers seems a simple answer to the question, *"Warum erblicken wir daher in der Spiegelschrift den Spiegel einer kranken Seele?"*[20]

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[17] This paper is not the place for a general evaluation of the concept of cortical localization. The writers cannot resist remarking, however, that much of the work in this field insofar as mirror-writing is concerned is the product of non-psychologically trained clinical neurologists and is characterized by sheer guesswork and by a surprising terminological anarchy, in which sensations and neurons, the will and brain centers, images and stimuli, march by in an Alice-in-Wonderland parade.

[18] Indeed, the earliest recorded case of mirror-writing which was considered scientifically was that of an epileptic girl of 21, reported by Dr. Rosenus Lentilius, in 1688. Cf. Wolzendorff (79). From this time down through the literature mirror-writing is often referred to as an unfavorable clinical sign. It is to be noted that the present cases were none of them superior individuals.

[19] In considering the importance of symmetrical movements of the two limbs in the production of mirror-writing, one should not lose sight of the facts that have been established and the psychological and neurological theories that have been proposed in regard to cross-education, or the bilateral transfer of learning. [Cf. Brady (13)]. A study of cross-education will show that mirror-writing is not unique in that it shows a relationship between the two sides of the body in motor action. It would be interesting, in view of a theory of mirror-writing, to determine to what extent transfer occurs when the effect of a performance learned by the right hand is tested in the left hand in its mirror image rather than in the same way in which it was acquired by the right hand.

In passing it may be noted that there seems little reason to assume that mirror-writing is characteristic of "moral perversion," "hysteria," or of "neurotic constitution," as has been suggested.[21]

The explanation of the fact that the phenomenon does occasionally occur in normal or even superior children is conceivably to be understood by considering the possibility that at the time that the integration of the script is developing some chance emotional response or other vivid experience leads to the peculiar reversal being thoroughly learned. The habits become so well established that the ordinary corrective of non-complete correspondence with the copy does not lead to the modification of the sequence involved before the integration by overlearning becomes so well established as to be only with the greatest difficulty eliminated.[22]

Some such individuals, like Leonardo da Vinci, so firmly integrate this form of writing that it is used by preference throughout life.[23] One case is reported of a physician who as a child wrote mirror-script. This was corrected. He found in medical school that he had trouble with written examinations. He could speak easily, however, in oral tests. He decided to try mirror-script. He says: "The first time I experimented I succeeded, to my surprise, with a rapid, perfectly formed, neat, even elegant, writing, infinitely better than the clumsy right-handed performance." He could, however, not read what he had written. He has continued for his own purposes, however, to write mirror-script on transparent paper (37).

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[20] In this connection it is interesting to note that more mirror-writers are found in the early years of school than in the later years. Cf. Lochte (49, p. 385).

[21] Cf., for example, Savage (61, pp. 568 ff.), and (60).

[22] This is, of course, not intended to introduce any new theory of learning, but merely to state, in as unambiguous terms as possible, the fact that all retention is not equally permanent. The concept of *vividness* is intended as descriptive. [Cf. Warren and Carmichael (76, pp. 183 ff.)] Thorndike's "after-effect" might equally well describe, although not explain the phenomenon [cf. Thorndike (73, pp. 30-81)]. One of the present writers has a characteristic flourish in the way in which he writes an *"f."* He well remembers that when he first made this flourish it pleased him. Since that time this particular flourish has appeared in much of his writing.

[23] Cf. Mills (53, p. 90) and Buchwald (17*a*, p. 8). Da Vinci's regression to this type of writing late in life, although possibly based on a gross structural change in the brain, is interesting to compare with other regressive phenomena.

For mirror-writing, as for any other inadequate childhood habit, to persist into adult life as the only means of writing is certainly an unfavorable clinical sign. Cahen-Brach's criterion of about ten years of age as marking the point after which mirror-writing, save as a "plaything," is to be considered abnormal, although arbitrary, seems to have much to recommend it (18).

In conclusion, it seems to the present writers that an understanding of the phenomenon of mirror-writing is important not only, as it has usually been treated, because of its undoubted significance in the problem of handedness and as a clinical symptom, but also because by a study of cases in which mirror-writing has spontaneously developed, new insight is gained into the fundamental psychology of the acquisition of motor and perceptual habits. A knowledge of the phenomenon shows, moreover, that if the analysis suggested in this paper is correct, a complex act which has been explained in terms of an often-times rather fanciful psychology of "attention," "brain centers," "complexes of imagery," "pictures in the memory centers," or "psychological governors" may at least, in a sense, be understood in a much less complex manner. Mirror-writing seems to be a product of a somewhat unusually directed process of normal human learning in which the usual corrective process of the elimination of non-adaptive acts has, for the reasons suggested above, stopped short of the last process of elimination which, had it been carried farther, would have made it a wholly satisfactory performance.

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UNE ÉTUDE DE L'ÉCRITURE DE MIROIR EN RELATION AVEC L'USAGE DES MAINS ET LES HABITUDES PERCEPTIVES MOTRICES

(Résumé)

1. Cet article présente une petite note historique et un résumé bibliographique des publications sur l'écriture de miroir ("mirror-writing") non comprises dans les études antérieures.

2. Il donne en détail les résultats d'étudier sept enfants qui ont montré une écriture spontanée de miroir. Dans chaque cas on présente des observations individuelles et donne les données suivantes: (*a*) âge; (*b*) Q.I.; (*c*) position scolaire; (*d*) l'usage des mains comme déterminé par des tests et par l'histoire sociale; (*e*) la vitesse et la qualité de l'écriture normale et de l'écriture de miroir; (*f*) l'habileté de l'indviduel pour le dessin.

3. On tire les conclusions suivantes sur la base des cas étudiés: (*a*) Ils ont montré tous une écriture frappante de miroir. (*b*) Dans chaque cas l'écriture de miroir s'est initiée spontanément. (*c*) La vitesse de l'écriture a été parfois plus grande, et parfois moins grande que celle de l'écriture normale sur le même sujet. (*d*) La qualité de l'écriture de miroir et de l'écriture normale produites par le même individu ont été différentes dans certain cas. (*e*) L'habileté de lire l'écriture de miroir et la typographie de miroir ont été différentes. (*f*) On a noté des particularités du dessin dans le cas de la plupart de ceux qui font l'écriture de miroir. (*g*) Il n'existe aucune uniformité absolue de la position de la main et de la main chez tous les sujets, pendant l'écriture de miroir. (*h*) Tous les cas, à l'exception importante d'un seul, ont été gauchers.

4. On critique les théories antérieurs de l'écriture de miroir, et on propose une théorie psychologique provisoire, laquelle comprend une considération de l'usage des mains et la nature du processus de l'apprentissage. A ce point de vue, on voit qu'une connaissance du développement génétique de l'écriture de miroir présente des témoignages importants sur la nature du développement de la perception ainsi que le développement cas habitudes motrices chez l'individu.

CARMICHAEL ET CASHMAN

EINE UNTERSUCHUNG DER SPIEGELSCHRIFT IM VERHÄLTNIS MIT DER HÄNDIGKEIT (HANDEDNESS) UND MIT PERZEPTUELLEN (PERCEPTUAL) MOTORISCHEN GEWOHNHEITEN

(Referat)

1. Dieser Aufsatz leifert eine kurze historische Anmerkung und eine bibliographische Zusammenfassung der in vorhergehenden veröffentlichten Untersuchungen über die Spiegelschrift nicht mit eingenommenen Arbeit.

2. Er liefert umständlich die Resultate einer Untersuchung an sieben Kindern, die spontane Spiegelschrift zur Schau stellten. In jedem Fall werden einzelne Beobachtungen dargeboten und folgende Tatsachen angegeben: (*a*) Alter; (*b*) Intelligenzquotient; (*c*) Schulrang; (*d*) Händigkeit so wie sich an Prüfungen und an der Anamnese des Gemeinschaftslebens des Kindes (social history) feststellen lies; (*e*) die Schnelligheit und die Qualität des normalen und des Spiegelschreibens; (*f*) die Gewandtheit des Individuums im Zeichnen.

3. Die untersuchten Fälle lieferten folgende Schlussfolgerungen: (*a*) Alle Kinder erwiesen ausgeprägte Spiegelschrift. (*b*) In jedem Fall kam die Spiegelschrift spontan zu Stande. (*c*) Die Schnelligkeit der Spiegelschrift war manchmal grösser und manchmal geringer als die des normalen Schreibens bei der selben Versuchsperson. (*d*) Die Qualität des normalen Schreibens und die der Spiegelschrift der selben Versuchsperson waren in gewissen Fällen verschieden. (*e*) Die Fähigkeit, Spiegelschrift und Spiegeldruck zu lesen, war verschieden. (*f*) Es zeigten sich bei der Mehrzahl der Spiegelschreibern Eigentümlichkeiten im Zeichnen. (*g*) Es gab keine absolute Uniformität der Arm-Hand Stellung bei allen Vpp. wärend des Spiegelschreibens. (*h*) Alle Fälle, mit einer wichtigen Ausnahme, waren Linkshändler.

4. Frühere Lehren von der Linkshändigkeit werden kritiziert, und es wird eine tentative psychologische Theorie vorgeschlagen, die eine Berücksichtigung der Händigkeit und der Beschaffenheit des Lernvorgangs in Anspruch nimmt. Von diesem Standpunkt aus zeigt es sich, dass die Kenntniss der genetischen Entwicklung der Spiegelschrift wichtiges Beweismaterial liefert in Bezung auf die Art der Entwicklung der Perzeption wie auch der motorischen Gewohnheiten des Individuums.

CARMICHAEL UND CASHMAN

RELATIVE EFFICIENCY OF RELAXATION AND TENSION IN PERFORMING AN ACT OF SKILL*

From the Psychological Laboratories of the University of Chicago

James T. Russell

Purpose

The purpose of the experiment is to compare the effectiveness of different degrees of muscular tension in an act of skill. The study is restricted to accuracy as the criterion of efficiency, and to tossing balls at a target as the act of skill. Three conditions of tension are employed. They are moderately tensed, natural, and moderately relaxed.

The problem may be stated as follows: To determine, for three conditions of tension of the bodily musculature, tensed, relaxed, and natural, especially for the arm and hand, in the case of tossing balls at a target, the absolute differences in accuracy, the influence of practice, the warming-up effect, the effect of change from one condition to another, the variability of performance, and sex differences.

Literature

Little literature bears directly upon the problem. Two sources of information have an indirect reference. The one concerns the influence of muscular tension upon the efficiency of mental work. The other concerns the nature of reaction movements and of muscular action.

Bills (1) found that muscular tension increases the efficiency of mental work. The mental work consisted of learning of nonsense syllables, addition, perception, and enunciation of letters of the alphabet. Two degrees of tension on a hand dynamometer were employed, the degrees being normal and greater than normal.

Stroud (5), in a study on the rôle of muscular tensions in stylus-maze learning, employed a pressure stylus and also an instrument to measure jaw tensions. He also induced tension artificially by requiring the subjects to pull upon a weight while tracing the mazes.

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Several mazes of varying difficulty were used. He found the following. There is a positive relation between tension and difficulty of task and between tension and speed of learning. Tension in the hand operating the stylus is increased by artificially induced tension in the other hand. There is a positive relation between artificially induced muscular tension and rate of learning.

Downey (2) found marked differences in the behavior of persons under tension. Some normally work under a load of varying amount, and are capable of much greater speed under stress. Others habitually work at or near maximum speed, and cannot change their efficiency under stress. Others react negatively to extra exertion, and their efficiency is decreased by their emotional attitude under tension.

The studies just mentioned have to do with complex mental reactions. However, tossing balls at a target is a comparatively simple muscular reaction. It is evident that, in the latter case, the mutual influence of simultaneously active muscle groups upon each other and their coordination of movement are important factors in determining accuracy.

Muscular action involves a double physiological action: contraction of the muscle producing the desired effect, and simultaneous relaxation of its opposing muscle. The one action causes the other. Thus, relaxation of a muscle is essentially an active process. Every contraction of considerable vigor requires the use of one muscle to prevent one of the two movements which another muscle can produce. Skill requires accuracy of movement and economy of force, or the use of the right muscles at the right time with the right amount of energy. The use of antagonistic muscles is essential. In all slow movements, the antagonistic muscles contract with the movers. If there is strong resistance, or if the movement is to be rapid, the antagonists do not contract and in many cases are inhibited.

Judd, McAllister, and Steele (3) studied the forms of final movement and the types of movement in the period of preparation and adjustment preceding the stimulus. They worked with the reaction key and recorded the movements of the subjects by means of a lever attached to the arm or finger. Variations in the movement of the lever were recorded on a kymograph. They found evidence of a rhythm of nervous action, wavy records of movements, which represented a rhythmical unsteadiness of muscular tension, or a balancing between the tendency to react with the antagonistic tendency. The latter tendency consisted in first pressing down on the key in an antagonistic reaction while attempting to lift the finger from the key. The final reactions filled out the regular rhythm of the whole line and came at the end of regular waves. The average length of wave was 145 sigma. They concluded that even a reaction movement is a complex process of adjustment. The general complexities noted were: waviness, preparation for reaction by a gradual or sudden antagonistic movement in the opposite direction, and a partial reaction, gradual or sudden, preceding the true reaction. There was a tendency for a subject to repeat a given type of behavior. The task required is an essential factor in determining the type of reaction movement.

Williams (6) extended the study of Judd, McAllister, and Steele. He found stronger attention associated with tense muscular preparation. Waves were less frequent than level lines or increases in pressure. This was probably due to the different conditions as compared with the above study. The wavy line towards the end of the reaction was the muscular accompaniment of anticipation of the stimulus. The waves were very uniform in length (about 100 sigma) and in amplitude.

Since the accuracy of movement involves extent, time, and force, and their proper coordination and control, any influence which affects any of the three factors may affect accuracy. It is evident that, in tossing balls at a target, even minimal, rhythmic unsteadiness of muscular tension can account in some measure for deviations from the true course of the ball. The period of the waves is at least one-tenth of a second, an interval great enough, in the case of a rapid motion of the arm, to make significant the fact that final reactions come at the end of regular waves. The question arises whether the period varies with the degree of muscular tension. If so, any differences in accuracy found among different degrees of tension might be explained in part on the basis of corresponding differences in period of the wavy movements. Possible differences in the extent of the antagonistic movement caused by differences in degrees of muscular tension might constitute another factor in the complex of factors causing differences in accuracy. The fact that subjects differ in the form of final movement of reaction and the fact that they tend to repeat a given type of behavior may account in part for individual differences in accuracy under the different conditions of tension.

THE EXPERIMENT

Standard tennis balls were thrown underhand from a distance of 17 feet through a round aperture of 8 inches diameter located in the middle of a board 4 feet long inclined at 45 degrees. The balls were of one weight.

A trial consisted of 50 tosses in timed succession at the rate of 4 per minute. Only 5 balls were used. After they were thrown, the experimenter recovered them and 5 more were thrown, and so on. Trials occurred 3 times a week, every other day, at the same time and under constant extra-organic conditions.

The criterion of efficiency was accuracy, or the number of successful tosses per trial. A successful toss consisted in throwing a ball through the aperture.

There were 40 subjects. All were unselected undergraduates.

Fifteen men and 15 women were placed in three initially equal groups of 10 each, each group containing 5 men and 5 women, by means of a preliminary experiment. This experiment consisted of 6 trials in which the subjects tossed the balls in a natural manner from a distance of 20 feet. The subjects were asked not to engage in any work similar to that of the experiment at any time other than that spent during the regular sessions, to cooperate in maintaining constant conditions, to be as accurate as possible for every toss, to remember that the conditions were so adjusted that it would be difficult to have many tosses succeed at first, to achieve scores as great as possible, to stand toeing the line of throw and not to move about during the trials.

For the main experiment, which began one week after the preliminary experiment, the three equal groups secured above were each assigned a certain condition for throwing—natural, tension, or relaxation. They threw in this manner for 22 trials, at which time the learning curves were approaching limits. Beginning with Trial 23 and continuing for 22 trials, the natural group remained under the natural condition, the tension group changed to relaxation, and the relaxation group changed to tension.

The remaining 10 subjects, 9 men and 1 woman, were given 12 trials, alternating tension and relaxation by trials. Five began with tension and ended with relaxation, and the other five began with relaxation and ended with tension in order to equalize the effects of practice. It was unnecessary to equate this group with the other groups since no comparison was made between the alternating group and the other groups.

Specifications for the three conditions are indicated in the following paragraphs.

During the week intervening between the preliminary experiment and the experiment proper, the subjects were taught how to throw in the proper manner. All received equal practice during this period. For each subject a demonstration was made of the method of throwing for his particular condition.

Relaxation subjects threw with the entire body relaxed, with just enough pressure in the right hand to hold the ball, and expelled the ball with a deliberate and easy sweep of the arm. Tension subjects threw with the entire body tensed, as in the muscular attitude when one prepares to meet an obstacle, holding the ball in a firm grasp, and expelling it with some force. The natural group threw as they normally would. They were informed of the conditions of tension and relaxation, and were instructed to maintain a muscular attitude between the two; that is, the natural attitude.

The duration of motion of the arm was approximately the same for all conditions.

The muscular sets for tension and relaxation were assumed just before throwing. Immediately after the toss, the subject assumed the natural condition. The maintenance of set lasted approximately 7 of the 15 seconds required for each toss.

At the beginning of each trial, the subjects were reminded of the conditions under which they were throwing. They were observed during the progress of each trial, and those who appeared to exaggerate the conditions were corrected. At intervals throughout the experiment, they were cautioned not to alter the assigned condition of throwing for any toss.

Throughout the experiment all subjects were keenly interested; they attempted to achieve scores as great as possible; and, as nearly as observation could determine, they maintained the conditions imposed.

Subjects were asked to submit, at the end of the trials, any observations and introspections which came to mind.

RESULTS

Table 1, in which the 44 trials are summarized for the three groups, indicates that, on the whole, the natural condition is slightly

TABLE 1

Condition	Mean score	*S.D.*	*V*	% Mean	% *S.D.*	% *V*
Natural	14.15±0.78	3.67	29.12	100.0	99.6	92.1
Relaxation	13.69±0.78	3.68	29.31	96.8	100.0	92.7
Tension	10.51±0.69	3.22	31.62	74.2	87.5	100.0

more efficient than the relaxed condition. The difference is 3.2%. The probable error of the difference indicates that there are 77 chances in 100 that the true difference is greater than zero, which in itself is not very significant. Yet this result is about the same for Trials 1-22 and for Trials 23-44; hence, there is some basis for the conclusion, even though the statistical criterion of true difference is low.

The natural is much more efficient than the tensed condition, the difference being 25.8%. The probable error indicates that there are 99 chances in 100 that the true difference is greater than zero.

The relaxed is much superior to the tensed condition, the difference being 22.6%. The probable error indicates that there are 97 chances in 100 that the true difference is greater than zero.

Comparison of the score made by any subject under tension with the score of the same subject under relaxation shows the following. For the tension-relaxation group, the mean scores are higher under relaxation except for one subject. In the relaxation-tension group, all subjects but two made lower mean scores under tension. In these two cases the differences are small.

For the alternating group, in which only six pairs of trials were given, the mean score for the relaxation trials (Table 2) was 11.8, and for the tension trials it was 8.7, a difference of 26%. This result is practically the same as that in the case of the other groups. Eight of the ten subjects made higher mean scores under relaxation, one did equally well under the two conditions, and one did slightly better under tension.

The practice curves for the natural, relaxation-tension, and ten-

TABLE 2

Trials	1 & 2	3 & 4	5 & 6	7 & 8	9 & 10	11 & 12	Av.
Av. score—relaxation	11.6	10.8	11.8	11.3	12.3	13.0	11.8
Av. score—tension	9.9	8.0	8.8	7.8	8.0	9.7	8.7

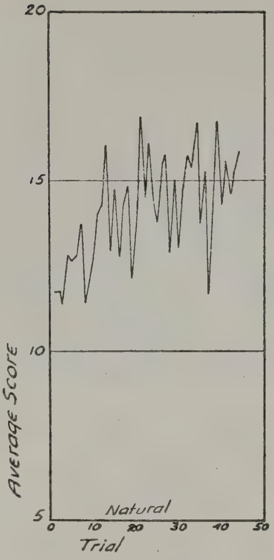

FIGURE 1

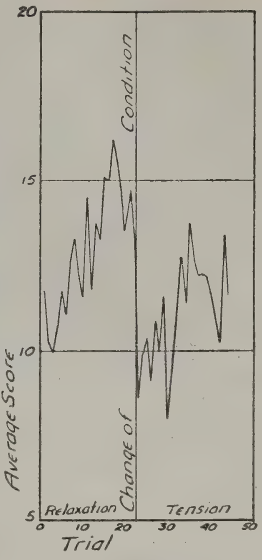

FIGURE 2

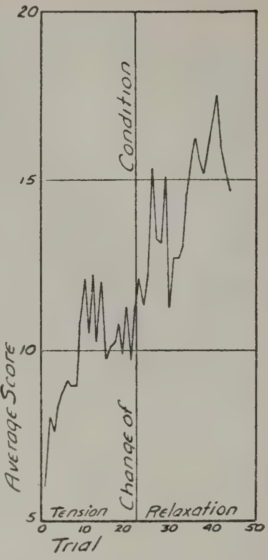

FIGURE 3

Figure 1: Progress of the "Natural" Group.
Figure 2: Progress of the "Relaxation-Tension" Group.
Figure 3: Progress of the "Tension-Relaxation" Group.

sion-relaxation groups are contained in Figures 1, 2, and 3, respectively. The practive curve of the natural group (Figure 1) is indicative of the customary curve of learning. A limit of performance is evident in the last 22 trials. Figure 2 is the practice curve of the relaxation-tension group. Under relaxation, the learning proceeded rapidly and at approximately a constant rate to Trial 17, after which it declined somewhat. The transition to tension caused a great decrease in efficiency on the first trial, after which there was relatively steady and marked improvement throughout. Figure 3 is the practice curve of the tension-relaxation group. Under tension, there is marked improvement for 10 trials, after which a limit is quickly reached. This approach to a limit within the first 22 trials is unique among the curves. The change from tension to relaxation caused only slight improvement during the first three trials, after which the gain was rapid until the last two trials. The final decline may be due to chance fluctuation.

Comparison of the practice curves of the three groups shows the following. For Trials 1-22, relaxation at first is slightly inferior to natural, after which the two conditions are about equal in efficiency. For Trials 23-44, the same effect is present, with the possibility that, if the trials were continued beyond the 44th, relaxation might become slightly more efficient than natural. For Trials 1-22, tension is clearly inferior to natural and relaxation conditions. The same is true of Trials 23-44, and over the course of the trials the differences are relatively the same in the two sets of trials. Under tension as the initial condition, improvement is more regular and rapid for the first 10 trials than under natural and relaxation, where they are the initial conditions. This may be the result of chance or it may be due to the possibility that tensed condition of throwing was the least practiced function before the experiment. For Trials 23-44, there is little difference in the general form of the curves for tension and relaxation. Tension is initially more irregular in this case than in the early part of Trials 1-22. Under tension, the subjects reached a limit of learning more quickly than under relaxation. This is especially evident in Trials 1-22. It must be noted that the three groups were equated originally on the basis of mean scores, and not on the basis of rapidity of learning or of regularity of performance. This fact may account for part of the differences among the three conditions stated above. For the tension-relaxation group, the slopes of both sections of the curve are steeper than the slopes of the curve for the natural group.

The effect upon one condition of practice upon a dissimilar condiition is summarized below.

Under natural conditions, the increase in mean score in going from Trials 1-22 to Trials 23-44 was 10%; for the tension-relaxation group the increase was 45%; and for the relaxation-tension group the decrease was 15%.

It is likely that only a small part of the great increase for the tension-relaxation group can be attributed to practice under tension. It can be reasonably expected that, under normal conditions, they too would have increased about 10%. The difference may be attributed to change from a difficult condition, to the fact that practice under tension constituted no practice for relaxation (the rapid improvement under relaxation in Trials 23-44 correspond to the usual rapid rise of the practice curve at the inception of learning), or the difference may be attributed to both. In view of the initial and continued rapid rise under relaxation, it is evident that the initiation of this condition, following tension, represented a change to a function that had little in common with tension, insofar as the effects of practice were concerned.

Change from tension to relaxation had little influence upon the practice curve for three trials, after which the improvement was marked. The initial slight change can be attributed to the persistence of the detrimental influence of tension, or to the difficulty of habituation to the new condition of relaxation, or to both. Change from relaxation to tension caused a great decline in the curve for the first trial, after which the improvement was marked. The pronounced decrement must be caused, for the most part, by the difficulty of the tensed condition.

Analysis of the primary data was made with respect to improvement within the trial, variability of performance, and sex differences. Improvement within the trial was analyzed from data showing the total frequency of successful tosses for each of the 50 attempts in the trial. The variability of performance is indicated in terms of the standard deviation (*S.D.*) and also in terms of the coefficient of variation (*V*). The analysis of the three factors indicated above is not elaborated here but is condensed in the summary of results below.

Summary of Results

These summarized results are applicable to the function of tossing balls at a target, under the conditions specified.

1. *Absolute differences in accuracy.*

   a. Average accuracy is slightly greater under natural conditions than under conditions of relaxation, but the difference is of doubtful reliability.

   b. The relaxation condition is clearly superior to the tension condition. Eighty-five per cent of the individual records conformed to this result.

2. *Influence of practice.*

   a. The initial advantage of the natural condition over the relaxation condition is decreased with practice.

   b. The initial advantage of the relaxation condition over the tension condition is maintained with practice.

   c. Subjects working under tension appear to reach a limit of accuracy more quickly than subjects working under relaxation.

3. *Immediate effect of change from one condition to another condition.*

a. Change from tension to relaxation has little immediate effect, but change from relaxation to tension produces a marked immediate decrease in accuracy.

4. *Warming-up effect and improvement within the trial.*

a. The warming-up effect lasts longer for tension and for relaxation than for the natural condition.

b. Initial warming-up is most pronounced for relaxation, less for natural, and least for the tension condition.

c. Transfer from the relaxation to the tension condition increases the warming-up effect, and change from the tension to the relaxation condition decreases the effect.

5. *Variability of performance.*

a. The differences in variability are not pronounced.

b. Variability appears to be a direct function of the difficulty of the condition.

c. Nearly one third of the subjects did not conform to this general rule. Hence, the effect of condition of tension upon variability is determined partly by individual differences in attitude toward the respective conditions.

6. *Sex differences.*

a. In general, women are less accurate than men.

b. Men perform relatively better than women under relaxation.

c. On the average, men profit slightly more from practice than do women.

d. Tension increases, and relaxation lowers, variability of men.

e. Tension and relaxation have about the same effect upon variability of women.

f. In general, women are more variable in performance than men, but the difference decreases with practice.

Interpretations

A better understanding of the influence of different degrees of tension upon physical accuracy can be obtained by an analysis of certain physiological and psychological factors which may be operative. A complex motor activity is not merely an aggregate of unit motor functions. The results obtained are conditioned by the various mental reactions operative under the different conditions.

Introspective reports indicated that tension might represent a less satisfying condition than relaxation or the natural state, especially in case of fatigue. But a condition of tension might also be associated with effective application to the task.

Downey (2) found marked differences in efficiency of persons under tension. The efficiency was conditioned by the customary mode of working and by the emotional attitude under different conditions of tension.

It may be expected that a tensed or relaxed set at the outset might produce a state of confusion or require attention to the fact of set and to its maintenance. Actually, this was found to be the case only for tension in the first three minutes of the trials. Again, it might be expected that, under tension, the attentive set might be longer maintained and more resistant to irrelevant stimuli. There is some evidence supporting this possibility in the fact that for the tensed condition no limit is approached for improvement within the trial, whereas limits are approached for the other conditions.

It is possible that the tensed condition represents *per se* a distraction to an extent greater than the relaxed condition. Introspective reports indicate that, under tension, attention was more upon the ball and less upon the target than under relaxation. This would account for part of the decreased effectiveness under tension.

Under tension and relaxation, the subjects paid more attention to the form of movement and to the general technic of throwing than under the natural condition.

The conditions of tension, though quantitative, were not determined in specific numerical terms. Uniformity was approximated by imitation and practice. Hence, there was an indeterminate range of fluctuation of the degree of tension maintained under each condition for each subject from day to day, and for subjects compared with each other. However, the difficulty would not be likely to result in gross uncertainties.

The degree of variability was found to be a direct function of the degree of tension. This may indicate, in part, that the above experimental error is greater for the tensed condition.

Individuals differ from one another in their degree of accuracy under the various conditions. The differences may indicate variable susceptibility to the effects of the conditions, but it is probable also that the subjects used different degrees and kinds of tension and relaxation. There were, doubtless, imperceptible shifts of individual technique from time to time. Very slight differences are significant in the case of tossing a ball 17 feet.

The differences between the natural and relaxation conditions were slight in most cases, so that they are not so readily intepreted as are the obvious differences between the natural and tension conditions, and between the relaxation and tension conditions.

Judd, McAllister, and Steele (3) and Williams (6) demonstrated the rhythmical unsteadiness of muscular action. Since the final reactions fill out the rhythm maintained between the tendency to react and its antagonistic, the question arises whether the amplitude and time of the muscular vibrations differ for different degrees of tension. The period of the waves was found to be over one tenth of a second. Any variation in the vibrations, due to different degrees of tension, might affect accuracy by changing the direction of the ball as it leaves the hand. The size of the error would depend upon the distance of the target.

Besides these minimal muscular variations, there are variations of a grosser nature. Subjects reported that, under tension, the time of greatest importance for accuracy was the instant of release of the ball from the hand. They stated that, at the time, under tension, there were frequently uncontrollable, jerky movements of the hand which caused the ball to leave the hand at a slight angle to the true trajectory. The tendency was much less pronounced for the relaxation and natural conditions. Observation indicated that the magnitude of divergence of unsuccessful tosses from the target was usually greater for tension. The fact that the subjects were more variable under tension adds support to the observation and report.

Another specific factor accounting in part for the loss in effectiveness under tension follows. Subjects reported that, under this condition, the balls at times did not leave the hand at the proper instant; there was a delay in opening the fingers enough to permit passage of the ball.

The weight of the balls may have been another determiner of accuracy. Balls of one weight were used throughout the experiment. Results may have varied somewhat if the weights of the balls and the degrees of tension had been related in some direct way.

It is of significance that muscular tension affected mental accuracy in the type of mental work in which Bill's subjects engaged differently than it did in the present experiment on physical accuracy.

Conclusions

The following general conclusions apply only to the particular conditions involved in this experiment.

1. The degree of accuracy and the degree of tension are inversely related.
2. The initial advantage in accuracy for relaxation remains approximately constant with practice.
3. The amount of warming-up effect within the trial varies directly with the degree of muscular tension.
4. The degree of variability is a direct function of the degree of tension.
5. Men are more adversely affected by tension than are women.

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LA VALEUR RELATIVE DE LA RELAXATION ET DE LA TENSION DANS L'ÉXÉCUTION D'UNE ACTION HABILE

(Résumé)

On a fait cette expérience dans le but de comparer la valeur de trois états de tension de la musculature du corps, tendue, relâchée, et naturelle, surtout au cas du bras et de la main, quand l'on jette des balles à une cible.

Résultats: Le degré de précision et celui de tension sont en relation inverse. Le premier avantage en précision pour l'état relâché reste approximativement constant avec l'exercice. La quantité de l'effet de l'exercice ("warming-up") dans l'épreufe varie directement avec le degré de tension. Le degré de variabilité est une fonction directe du degré le tension.

Russell

DIE RELATIVE WIRKSAMKEIT DER ENTSPANNUNG UND DER GESPANNTHEIT BEI DER AUSFÜHRUNG EINER GESCHICKLICHKEITSHANDLUNG (ACT OF SKILL)

(Referat)

Das Ziel des Versuches war, die Wirksamkeit dreier Spannungszustände der Körpermuskulatur—die eines gespannten, die eines entspannten, und die eines natürlichen Zustandes—besonders im Arme und in der Hand, bei der Bewerfung einer Tartsche mit Bällen zu vergleichen.

Befunde: Der Genauigkeitsgrad ist der Spannungshöhe entgegengesetzt, (inversely related). Die anfängliche Ueberlegenheit des entspannten Zustandes in Bezug auf Genauigkeit bleibt im Verlauf der Uebung ungefähr konstant. Der Betrag an Anfeuerungswirkung (warming-up effect) innerhalb des Versuches variirt direkt mit der Spannungshöhe. Der Variabilitätsgrad ist eine direkte Funktion der Spannungshöhe.

Russell

AN EXPERIMENTAL STUDY OF EQUIVALENT STIMULATION IN HUMAN LEARNING*†

From the Psychological Laboratory of the University of Arkansas

Robert Leeper and Dorothy Olson Leeper

The Problem and Its History

The present experiment aims to illuminate some hitherto relatively untouched aspects of the question as to whether learning can possibly depend, neurologically, upon the reduction of resistance along definite neural paths, or whether, quite on the contrary, learning must be conceived of as being dependent upon neural changes which somehow function by processes in which the pattern or organization of neural activity aroused, rather than the specific pathways involved, would be the indispensable condition of habit-formation.

There are, of course, a considerable number of experiments which have thrown light on the general problem indicated above. For example, the studies of perception by Gestalt psychologists have led them to develop and test a theory of dynamically-organized nervous processes in perception, and they also have come to utilize this theory in the study and explanation of learning. In addition, there have been quite a few other experimental studies bearing directly on the question. The majority of these may perhaps best be described as dealing with the phenomenon of "equivalence of stimuli" or, for reasons that will be explained later, "equivalent stimulation." Of course, only relatively few of these studies have been reported under either of these labels. Also, only a part of these studies have been interpreted by their authors in the way here done. Nevertheless, they afford an easily recognized and easily integrated group of studies from this point of view. Two slightly different types of procedure have been used in these studies. The one procedure has been this: first, the subject is trained, by repeated trials with the same stimulating situation, to make a certain reaction. Then, the habit once established, the stimulus of the training period is replaced success-

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ively by other stimuli, the object being to determine whether any other stimuli would produce the same reaction. Lashley (10, 11) and Klüver (7) have utilized this method in an effort to determine in some detail the nature of the brain mechanisms involved in learning. They have sought to attain this end by using a great diversity of substituted stimuli to determine how a substituted stimulus must be related to the stimulus of the training period to be equivalent to it in evoking the learned response. It has been found that the stimuli may be modified quite radically without destroying their equivalence.

The second basic type of procedure in these experiments is differentiated from the first by the fact that, at the conclusion of the training, the change in the stimulating situation consists in applying the stimulus of the training period to an hitherto untrained part of the sensory surface. Thus, Franz (2) trained subjects to identify certain geometrical forms when these were presented to a certain peripheral retinal area. After considerable accuracy was attained, test trials were given in which the forms were presented to other peripheral regions equally distant from the fovea. This changing of the region stimulated resulted in only slightly diminishing the percentage of forms recognized. This second type of experiment is that which we had in mind when we suggested above that the term "equivalent stimulation" could well be substituted for "equivalent stimuli." Since this somewhat broader term not only more sensibly designates the situation in Franz's experiment, but also indicates the situation in the first type of experiment as well, we shall employ it hereafter with both types of experiment.

In surveying the literature on equivalent stimulation and learning, one finds that the available studies fall more or less naturally into two classes. The first class consists of those studies which have served merely to call attention to the phenomenon and prove its reality. Hunter (3), for instance, in 1918, found that some rats, after they had been trained in a T-maze to make discriminatory reactions to sound and silence, respectively, reacted in a corresponding fashion when light and darkness were substituted for sound and silence. In Watson's famous experiment (18) in which an infant was negatively conditioned to a white rat, it was found that the conditioned child made almost equally intense avoiding reactions to rabbits or dogs or to the touch of a fur collar. Munn and Stiening (14), despite the fact that they interpret their results as antagonistic to Gestalt principles, have shown that for a 15-months-old child quite a range of geometrical patterns will be equivalent to certain standard patterns of the training period. Dunlap, Gentry, and Zeigler (1) have reported that when rats have been trained to move between two adjoining compartments in response to electric shocks the same behavior is evoked by auditory stimulation. M. C. Jones (5), in the reconditioning of a child afraid of dogs and other furry animals, found that reconditioning the child by bringing a rabbit closer and closer to the child during his morning lunch on successive days had the effect of changing the reaction to other animals also. Lashley (9) found that rats that had been trained to choose between two different light intensities when trained with one eye blindfolded reacted with equal facility when the blindfold was transferred to the other eye. Köhler (8, pp. 216-217, 302-303), in experiments designated by him as transposition experiments, found that chicks that had learned to react positively to a medium gray when a medium and a light gray were presented would react positively to a dark gray when a dark and a medium gray were presented together. Perkins and Wheeler (17) have reviewed briefly quite a few other studies very similar to this transposition experiment by Köhler. The earliest of these was reported in 1902. There are also undoubtedly other studies analogous to the above.

The second class of experiments which one finds in reviewing the work on equivalent stimulation is the group of studies made with the deliberate intention of exploiting the principle of these experiments to gain a more detailed picture of brain mechanisms. This group includes Pavlov's studies of initial generalization (15, pp. 112-117), Loucks' (13) recent repetition and revision of Pavlov's work on this problem, Lashley's studies (10, 11) of form-discrimination habits in rats, Klüver's extensive work (7) with monkeys, and Yum's work (20) on the "law of assimilation."

From these studies a number of principles seem established: First, after a habit has been established, quite marked changes may be made, either with regard to the stimulus presented or with regard to the sensory region stimulated, and the habitual reaction which has been developed will nevertheless be evoked. Secondly, as regards the characteristics which make different stimulations equivalent, two generalizations may be formed: (*a*) when the experiment is such that the animal has to discriminate between different stimuli presented, other stimuli presented in the same sense field will be at least roughly equivalent if they present somewhat the same balance or pattern of stimulation (there are certainly limits to this statement, but what they may be remains undetermined); and (*b*) when the animal has to make a reaction to a given signal in a given experimental setting (even a discriminatory response, with one of the alternative responses attached to an absence of this special stimulation), the stimulation can be shifted even to another sense field and yet govern the reaction. Of course, the above principles are still but vaguely and crudely defined, but they are sufficiently amply demonstrated to establish the general principle that in developed habits the general pattern of stimulation, rather than the receptor region or the neural region involved, determines the functioning of the habit.

In the present investigation, we have sought to extend these previous studies of equivalent stimulation by means of the technique of careful quantitative determination of the relative rates of learning under the condition of varied stimulation (with the internal pattern of the stimuli left the same) and under the condition of constant stimulation. This technique was deemed worthy of trial because it was thought that it would throw light on the two questions of whether equivalence of stimulation is characteristic of the earlier stages of learning and whether the mechanisms governing equivalence of stimulation are presumably the same mechanisms as those of ordinary learning with constant stimuli. Most psychologists, even those somewhat familiar with the phenomenon of equivalent stimulation, have not modified their theories of learning in the manner required to account for the phenomenon. It is as though they considered the phenomenon a rare peculiarity of the learning process—something that could be accomplished only by some unusual activity or expenditure of energy on the part of the nervous system (relational judgment, or something similar). The present experiment has sought to throw light on the question as to whether this is the case or whether the mechanisms of ordinary learning should be conceived of in the same dynamic terms that have alienated so many people from Gestalt psychology, but which seem indispensable for the description of established habits.

General Methodological Principles

To find an answer to the questions outlined above, the present investigation has used a procedure which employs in a controlled manner the situation which analysis reveals in almost all of ordinary learning. That is, certain habits were established by courses of training in which different stimulation was given in each trial, the difference between the stimulations being a matter of their absolute qualities and not of the internal pattern or organization of the stimuli. The rapidity of learning under these training conditions was compared with the rapidity of learning by control groups presented with the same situation in every trial. This procedure[1] was chosen with the belief that if learning proceeded at about the same rate under the two conditions this would constitute very powerful proof that the essential physiological changes upon which learning depends are changes which function by reason of the patterns of neural activity involved rather than by reason of the particular pathways.

One precaution has been particularly observed in choosing materials with which to experiment. There are certain possible learning materials which would surely possess some degree of equivalence, but which would have constituted poor materials for our experiment. The material to which we refer is that which possesses what might be called *habit-derived equivalence*.[2] For example, synonyms like "house" and "dwelling" are roughly equivalent stimuli for English-speaking people because of the language training which these people have. Or again, it might be argued (even though most psychologists might dissent), that we tend to respond with the word "red" to a variety of colors containing an admixture of red, not because of any generalizing capacity of the nervous system, but because our parents, playmates, etc., during the period of our early language training, pointed to such a variety of colors and assured us solemnly that they were all "red." In such a case as this it may be difficult practically to determine whether we have a case of habit-derived equivalence or a case of what we will call sensory equivalence, but the theoretical distinction between the two is easily defined. One might perhaps well designate them as learned equivalence and instinctive equivalence except that the use of the latter expression would evoke too many confusing connotations. But let us return to the discussion of our experimental methods. Suppose for the moment that the training theory mentioned above is the real reason why people designate as "red" a great variety of shades and hues, and react analagously to other colors. If an experiment were then conducted to discover whether people can learn as rapidly to react in certain ways to the different major colors when these are varied in hue, etc., on successive trials as when they are always presented in the same fashion, the results of the experiment would be of quite uncertain significance. For, in such a case, the subjects, in learning their associations to the different colors, might with every stimulation interpose between the sensory activity and the final association-response the intermediate implicit response of naming the color. If this were done the subjects might learn the associations to the different colors as rapidly when they were varied as when kept constant, even though the nervous system functioned in the specific-path fashion hypothecated in the traditional learning theory, for in every trial the subjects' color-naming habits would provide a constant and unvarying implicit stimulus with which the final response might be associated.

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[1] So far as we have discovered, the only studies which have previously used a technique analogous to this are Lewis' work with chicks (12) and Perkins' work with goldfish (16). Each of these experimenters interpreted his results as indicating that with varied stimulation learning proceeded more rapidly, and Perkins, in particular, goes into quite a discussion of the theoretical importance of this result. On examining Perkins' data we find that there were but 9 goldfish in each of the compared groups and that there was nothing but the simplest examination of the data statistically. On calculating the standard errors, etc., we find that the group difference stressed so strongly is less than 1/10 of the *S.E.* of the difference between the means! Of course, the rejoinder to this might be: you can't use statistical formulæ on groups of that size. But the rejoinder has no point. If groups are too small to treat statistically they are too small to justify any discussion at all of group differences, as many a statistician has pointed out. With regard to Lewis' experiment, it is impossible to evaluate the accuracy of his interpretation, as very little specific information is given. His groups were small, however, and his experimental procedure was hardly adapted to answer the question at stake.

We would here acknowledge the work of Perkins and Lewis as having suggested the essential technique of the present investigation except for the fact that we did not know of their work until the present study was completed.

[2] Weiss has stressed considerably this sort of equivalence (for example, see 19, pp. 309-333); Hunter (4, pp. 318-321) likewise has emphasized the importance of such equivalence, although also giving illustrations of what might be called *sensory equivalence.*

In other words, for our investigation to answer the theoretical questions with which it is concerned, materials were required of such a nature that the various variations employed would not be equivalent as a consequence of habits of the subjects. Or, using the expression suggested above, the soundness of this experiment depends upon the degree to which we have employed materials possessed only of sensory equivalence. In the following pages, in connection with the more detailed descriptions of the materials of our investigation, the reasons will be indicated for believing that the learning problems selected meet this qualification.

General Materials and Procedure

The apparatus, procedure, and results of each of the sub-experiments are reported below as a unit for each experiment. However, a few features characterized all experiments and may be described here.

Four different types of learning material were used: a pencil maze, a number maze, some simple piano melodies, and some rhythms. All of the materials were of a sort adapted for group presentation, and all of the experiments were administered accordingly, with the number of subjects tested at a time ranging from 6 to 30. In the melody and rhythm experiments the same subjects served with the constant and varied material intermingled; in the pencil-maze and number-maze experiments half of the subjects at each sitting were used with the varied material and the other half with the constant material. These means were used to secure approximately even distribution of ability and equating of experimental conditions. All of the subjects were university students ignorant of the purpose of the experiment. The instructions in the different experiments, rather than being given in any rigidly standard form, were elaborated slightly or repeated to whatever extent appeared necessary to secure clear understanding of the different points of the instructions. These variations in the mode of giving instructions were deemed permissible in view of the fact, as noted above, that each body of students tested was divided evenly between the two conditions compared, and because of the great importance of clear understanding of instructions in such group work.

The Pencil Maze Experiments

The first two experiments utilized the rather complex pencil maze shown in Figure 1. The constant subjects had this same maze, drawn to the same scale (5½" x 7½", printed on 8½" x 11" sheets of paper) on trial after trial. The varied subjects likewise had the same pattern of maze on every trial, but, except for certain scattered trials, the maze was drawn on a different scale for each succeeding trial. There were 8 such variations in scale, the variations ranging from 1/3 smaller than the constant size to 1/3 larger. All of these varied sizes were printed on 8½" x 11" sheets, as were the constant

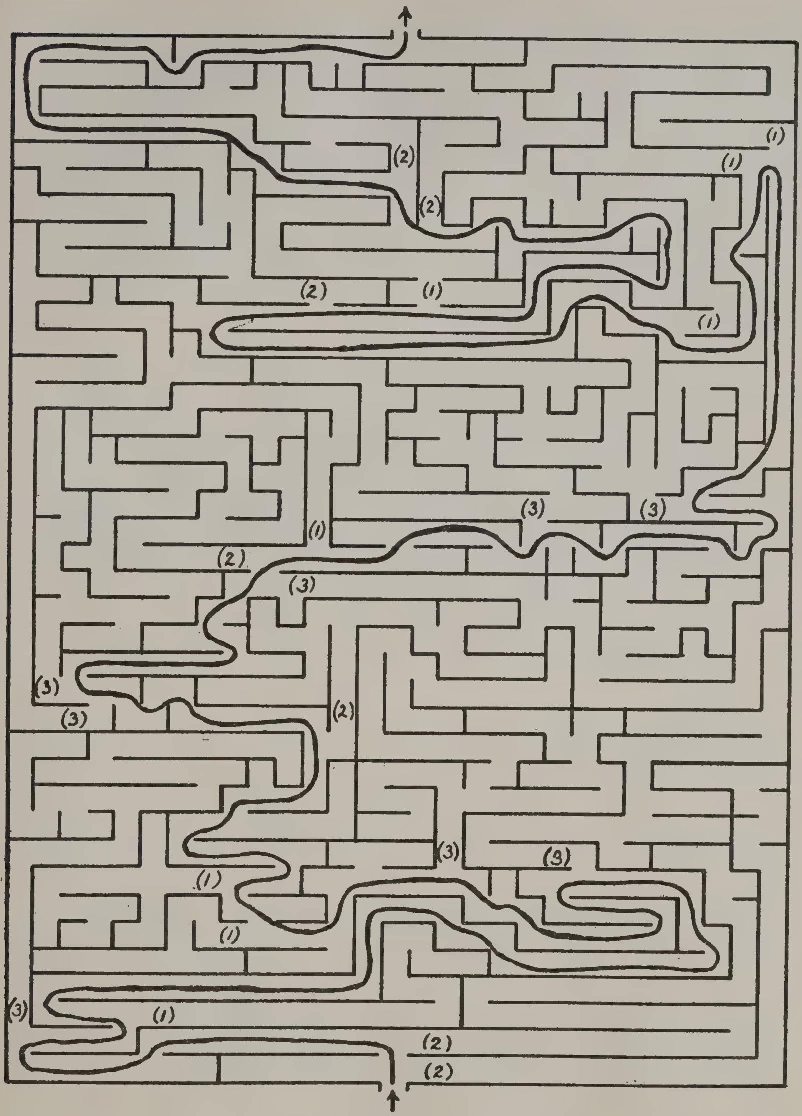
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FIGURE 1

The Pencil Maze with the Correct Path Traced Thereon

The figures at the entrances to the various blinds indicate the relative credit allotted for going beyond each of the same.

sizes, except the two smallest variations, which were printed on 5½" x 8½" sheets. This latter fact probably hampered slightly the learning of the varied subjects, for prior to the trials with the regular maze two preliminary trials were given with simpler mazes to insure clear understanding of the instructions, and these simpler preliminary mazes were also printed on the 5½" x 8½" sheets, so that some varied subjects, on coming to the two smallest regular patterns, thought that their sheets must have been mixed up, and were consequently momentarily confused in their work.

The instructions given in the pencil maze experiments were as follows:

> "You will be given a complicated figure with a path running continuously from the start, which is indicated at the bottom of the sheet by an arrow pointing into the figure, to the finish, which is indicated at the top of the sheet by an arrow pointing out of the figure. Trace a continuous line from the start towards the finish. If you enter any blind alleys, trace your way back out of them and proceed on the correct path. The sheets will be passed out to you upside down. When the experimenter says 'Go,' turn the top sheet over and start working. When the experimenter says 'Stop,' stop immediately and mark an X at the point where you are; then turn that sheet over immediately, put it under the other sheets, and wait for the next trial."

As mentioned above, before the regular sheets were passed out, two preliminary practice mazes were used. The first was a very simple maze, the second was moderately complex. Each of them illustrated to some extent some principles of the construction of the regular maze such as the general bottom-to-top direction, the style of blinds, etc.

The principal method of scoring was as follows: As indicated on Figure 1, the blinds were not scored as though of equal difficulty, but were given values ranging from 0 to 3. In all, 46 points could be secured per trial, and subjects were scored in terms of the percentage of these 46 points secured. If a subject had traced to a certain point by the time that the stop signal was given he received credit for passing all of the blinds that lay between that point and the start, regardless of whether he had traced into any of them or not, except that if he had ended in a blind that blind was not credited to him. In the first experiment a second method of comparing the varied and constant subjects was also possible—comparing them in terms of the percentages of the two groups traversing the whole maze on the different trials.

It has been said that there were two pencil maze experiments. They differed only on these points: (1) in the first experiment conducted, 2′ was allowed for trial 1 and 1′ for each succeeding trial; in the second experiment only 1′ was allowed for trial 1 and 45″ for each other trial; (2) in the second experiment a recall trial was given 17 to 19 days after the main group of trials; and (3) in the first experiment the varied subjects had the constant size of maze

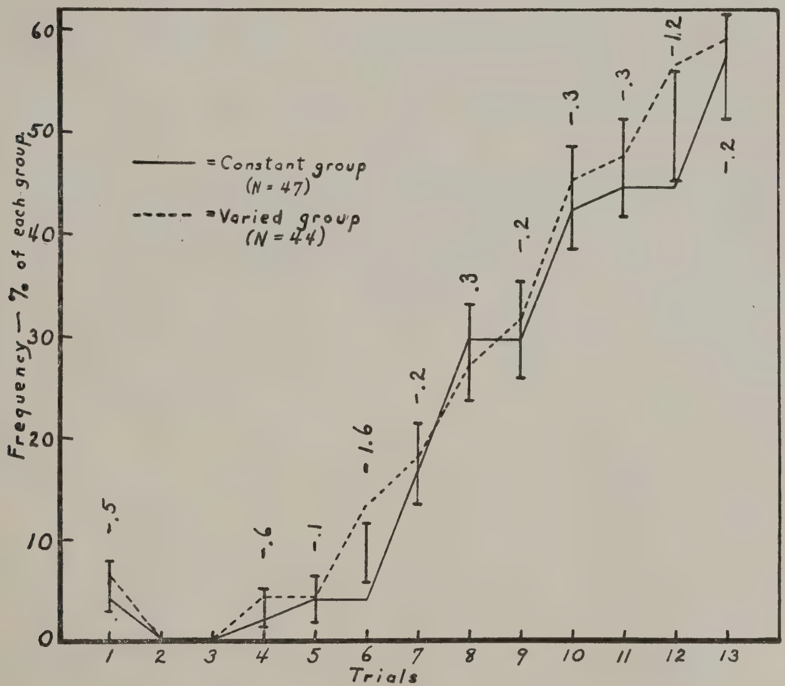

FIGURE 2

Results of the First Pencil Maze Experiment in Terms of the Percentage of Each Group Finishing the Maze Within the Time Limits

The vertical bars indicate $S.E._{diffs.}$. The numbers above the curves indicate $\frac{\%_c - \%_v}{S.E._{diff.}}$. The varied subjects had the constant-size maze on Trials 1, 4, 7, 10, and 13.

on Trials 1, 4, 7, 10, and 13; in the second experiment the varied subjects had this constant size maze only on Trials 1, 6, 11, and on the recall trial.

Results. The first comparison of the rate of learning of the varied and constant groups in the first pencil maze experiment is given in Figure 2, which shows the percentage of each group traversing the entire maze on the different trials. It can be seen that, as measured by this criterion, the varied subjects learned the maze somewhat more rapidly than the constant subjects, but the group differences are not reliable.

In terms of the median percentage of blinds passed on the different trials, the relative performance of the two groups is shown in Figure

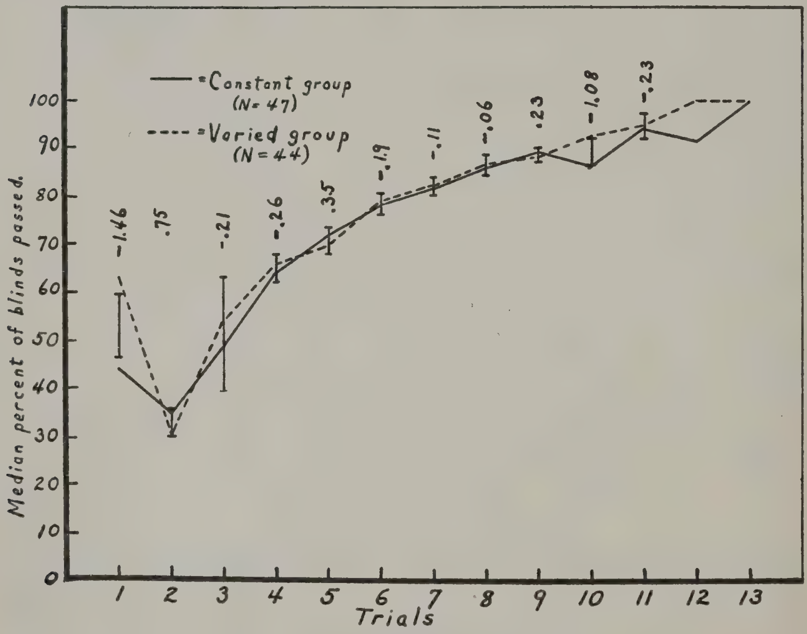

FIGURE 3

RESULTS OF THE FIRST PENCIL MAZE EXPERIMENT IN TERMS OF THE MEDIAN PERCENT OF BLINDS PASSED

The vertical bars indicate $S.E._{diffs.}$. The numbers above the curves indicate $\frac{Mdn_c - Mdn_v}{S.E._{diff.}}$. The varied subjects had the constant-size maze on Trials 1, 4, 7, 10, and 13.

3 and Table 1. The strikingly close correspondence between the two learning curves after Trial 1 is the most obvious thing about these data, but one consideration changes the picture somewhat. As shown, on Trial 1 the varied subjects scored appreciably higher than the constant group. This was true of the means as well as of the medians. The mean percentages of blinds passed by the varied and constant subjects were 53.7 and 45.7, respectively, with the difference 1.26 times its *S.E.* Whether this difference resulted from chance or from some superiority of the varied subjects at this task cannot be said, but in either case the better performance on Trial 1 would tend to give them a continuing advantage on the remaining trials. Considering this factor, one would be inclined to say that the constant subjects learned somewhat more rapidly. However, this conclusion is opposed by two other considerations: First, on the

TABLE 1

RESULTS OF THE FIRST PENCIL MAZE EXPERIMENT IN TERMS OF THE MEDIAN PERCENTAGE OF BLINDS PASSED BY THE CONSTANT AND THE VARIED GROUPS

	Constant group ($N = 47$)		Varied group ($N = 44$)		$\frac{Mdn_c - Mdn_v}{S.E._{diff.}}$
Trial	Median score	$S.E._{mdn}$	Median score	$S.E._{mdn}$	
1	44%	7.5%	63%	10.7%	—1.46
2	35	5.0	30	3.0	.75
3	49	8.9	54	21.6	— .21
4	64	4.5	66	3.9	— .26
5	72	4.1	70	3.9	.35
6	78	3.2	79	3.1	— .19
7	82	2.5	82	2.9	— .11
8	86	2.8	86	3.3	— .06
9	89	2.8	88	2.9	.23
10	86	3.4	93	4.8	—1.08
11	94	3.1	95	4.8	— .23
12	91	2.5	100	—	—
13	100	—	100	—	—

Note: Each $S.E._{mdn}$ was figured by the formula: $S.E._{mdn} = \frac{i\sqrt{N}}{2f}$ [see Kelley (6, pp. 90-91)]. In the calculation of both the medians and $S.E._{mdn}$'s the data have been treated in a manner analogous to that which Kelley explains (6, p. 54). That is, if *n* subjects had traced past a certain blind, but not past the following blind, it was assumed that most probably these *n* subjects were about evenly distributed between the condition of having solved merely that passed blind and the condition of having solved the succeeding blind, and the scores were dealt with correspondingly.

TABLE 2

RESULTS OF THE SECOND PENCIL MAZE EXPERIMENT IN TERMS OF THE MEDIAN PERCENTAGE OF BLINDS PASSED BY THE CONSTANT AND THE VARIED GROUPS

The figures for the retested subjects involve mean scores. Thirty-one constant subjects were retested, and 27 varied subjects. The retest was given 17 to 19 days after the main trials.

Trial	Constant group ($N = 46$) Median score	Constant group ($N = 46$) $S.E._{mdn}$	Varied Group ($N = 43$) Median score	Varied Group ($N = 43$) $S.E._{mdn}$	$\frac{Mdn_c - Mdn_v}{S.E._{diff}}$
1	26%	2.0%	21%	2.4%	.83
2	26	2.0	25	2.0	.24
3	28	3.2	29	3.0	— .35
4	41	4.9	35	4.7	.97
5	33	5.5	37	8.5	— .36
6	37	7.4	49	.7	— .92
7	61	6.3	42	4.7	2.33
8	61	7.4	46	8.5	1.35
9	68	5.5	65	4.7	.45
10	73	5.5	65	8.5	.75
11	78	4.0	71	3.9	1.38
Tr. 11 (*S*'s given retest)	79	5.2	70	3.8	1.33
Retest	46	9.7	63	6.8	—1.45

Note: For methods of calculating the medians and $S.E._{mdn}$ see the footnote to Table 1.

second trial the varied subjects lost their lead. Whether this was a chance event or the result of confusion from unexpectedly coming upon a different size of maze is unknown, but their initial advantage was certainly lost. Secondly, on the later trials the varied subjects actually did surpass the constant subjects. On 9 of the 12 trials after Trial 1 the varied subjects had the higher median scores.

As regards the second pencil maze experiment, the results are shown in Figure 4 and Table 2. In this experiment the constant group had somewhat of an advantage on Trial 1, but the varied group kept abreast through the first 6 trials and even after that did not fall reliably behind. On the recall test, given 17 to 19 days after the main group of trials to the 31 constant subjects and 27 varied subjects then available, the varied subjects gave evidence of better, but not reliably better, recall. (The recall scores and scores on the eleventh trial are given for these recall groups in terms of the mean scores, both in Figure 4 and Table 2.) The difference

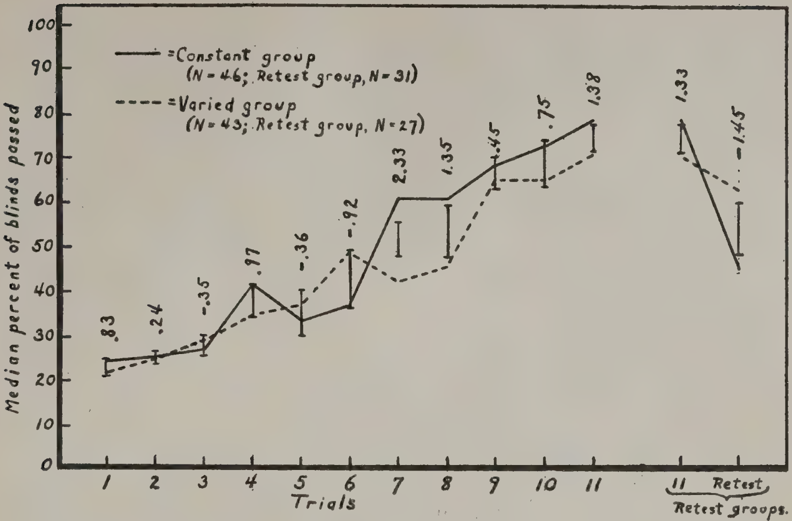

FIGURE 4

RESULTS OF THE SECOND PENCIL MAZE EXPERIMENT

The vertical bars indicate $S.E._{\text{diffs.}}$. The numbers above the curves indicate $\frac{Mdn_c - Mdn_v}{S.E._{\text{diff.}}}$. The varied subjects had the constant size maze on Trials 1, 6, and 11 and on the recall. The scores of the retest groups on both Trial 11 and the retest are mean scores rather than median scores. The interval between the 11th trial and the retest was 17 to 19 days.

between the mean recall score and mean 11th-trial score for the constant subjects was 8.2% of the blinds (with a $S.E.$[3] of 2.05), and the corresponding difference with the varied subjects was 5.6% (with a $S.E.$ of 2.37); but the difference between these two differences was only .84 times the $S.E.$ of that difference. Accordingly, in the second pencil maze experiment, as in the first, it appears that varying the scale to which the maze is drawn does not seem to affect in any certain way the rate of learning of the maze. If there is a tendency for the constant subjects to learn more rapidly, the difference is hardly greater than might result from several considerations

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[3] Throughout this study, in every case where a difference involved scores that could be correlated, the standard error of the difference was calculated by the formula:

$$S.E._{\text{diff.}} = \sqrt{S.E.^2_{M_1} + S.E.^2_{M_2} - 2r_{1.2} \cdot S.E._{M_1} \cdot S.E._{M_2}}$$

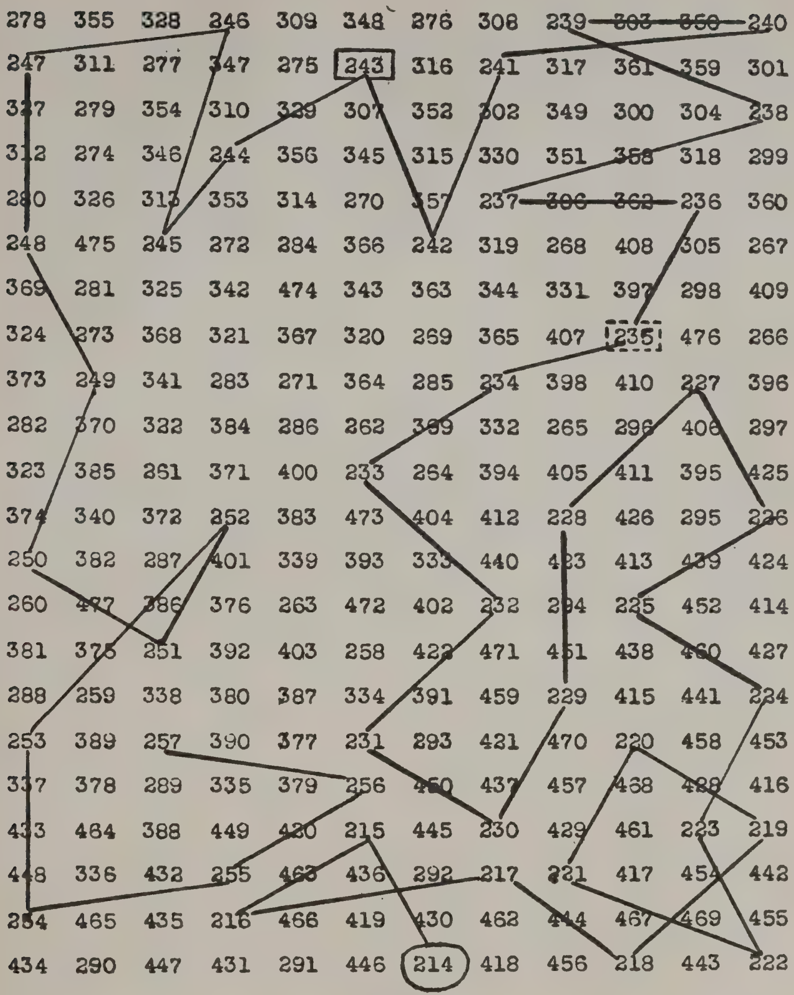
really extraneous to the learning situation—for example, the momentary confusion that tends to result from getting quite a different size of maze (and sometimes, as noted above, on a size of paper which led some subjects to feel for a moment that some of the preliminary mazes had been mixed with their material).

This further question must be considered, however: Are pencil mazes of different scale but similar pattern equivalent as learning material because of some habit-derived equivalence or because of sensory equivalence?—will not the subjects guide themselves by "Right, forward, left, left . . ." formulations (or by "turning habits") to such an extent that the experiment will have all the defects indicated above in the discussion of general methodological principles? The answer is that the chief reason for believing that the pencil maze experiments satisfy the requirements of our investigation is that individuals who learn such a complex pencil maze become impressed with the feeling that they are not learning by some process of verbalization, but rather by the building up of perceptual habits not essentially verbalized in nature. This feeling, furthermore, receives objective support from the next experiment reported, for in it, with some of the perceptual cues removed but with no interference with possible turning habits or "Right, forward, left, left . . ." formulations, the learning was much slower than with the material left unchanged. We cheerfully admit that if a good case could be built up for an interpretation of pencil-maze learning opposite to that which we have given, the results of these experiments could, of course, not be utilized as evidence for the pattern theory of learning.

The Number Maze Experiment

Before the number maze experiment was performed it was anticipated that the variations employed in it would cause no greater hindrance to learning than the variations in any of the other experiments. Quite the opposite result was found. The value of this experiment, therefore, is derived from the light which it throws on the question of what characteristics of different stimuli cause them to be equivalent.

The materials used in this experiment are illustrated in Figure 5, except that on this figure the correct path has been traced over the portion of the route exceeded by only a few subjects, and except for the few details of the results which have been indicated on the maze. The subjects in this experiment were instructed that they



278	355	328	346	309	348	376	308	239	303	350	240
247	311	277	347	275	243	316	241	317	361	359	301
327	279	354	310	329	307	352	302	349	300	304	238
312	274	346	244	356	345	315	330	351	358	318	299
280	326	313	353	314	270	357	237	306	362	236	360
248	475	245	272	284	366	242	319	268	408	305	267
369	281	325	342	474	343	363	344	331	397	298	409
324	273	368	321	367	320	269	365	407	235	476	266
373	249	341	283	271	364	285	234	398	410	227	396
282	370	322	384	286	262	399	332	265	296	406	297
323	385	261	371	400	233	264	394	405	411	395	425
374	340	372	252	383	473	404	412	228	426	295	226
250	382	287	401	339	393	333	440	423	413	439	424
260	477	386	376	263	472	402	232	294	225	452	414
381	375	251	392	403	258	422	471	451	438	460	427
288	259	338	380	387	334	391	459	229	415	441	224
253	389	257	390	377	231	293	421	470	220	458	453
337	378	289	335	379	256	450	437	457	468	428	416
433	464	388	449	420	215	445	230	429	461	223	219
448	336	432	255	463	436	292	217	221	417	454	442
254	465	435	216	466	419	430	462	444	467	469	455
434	290	447	431	291	446	214	418	456	218	443	222

FIGURE 5

Typical Sheet from the Number Maze Experiment

The correct path is traced up to the point exceeded by only a few subjects. The solid rectangle indicates the mean of the constant subjects on the last trial; the dotted rectangle the mean of the varied subjects on the same. The starting point was indicated on each sheet by the circle around the smallest number. Variations of the number maze were secured by adding to or subtracting from each number in the maze certain set sums.

were to be given mimeographed sheets covered with 3-place figures, that the smallest figure on the sheet would be indicated by a circle at the bottom of the sheet, that they were to draw a line from this smallest figure to the next larger, etc., for as great a distance as they could go within the time allowed, and that they were to keep the sheets upside down on their desks except between the signal to start and the signal to stop on each trial. They were also informed that there were no missing numbers and no duplicate numbers, and that they might economize on their time by not searching for the next larger number any further than about 2½″ in any direction from the last figure located. Two minutes were allowed for the first trial and 1′ for each of the 14 succeeding trials.

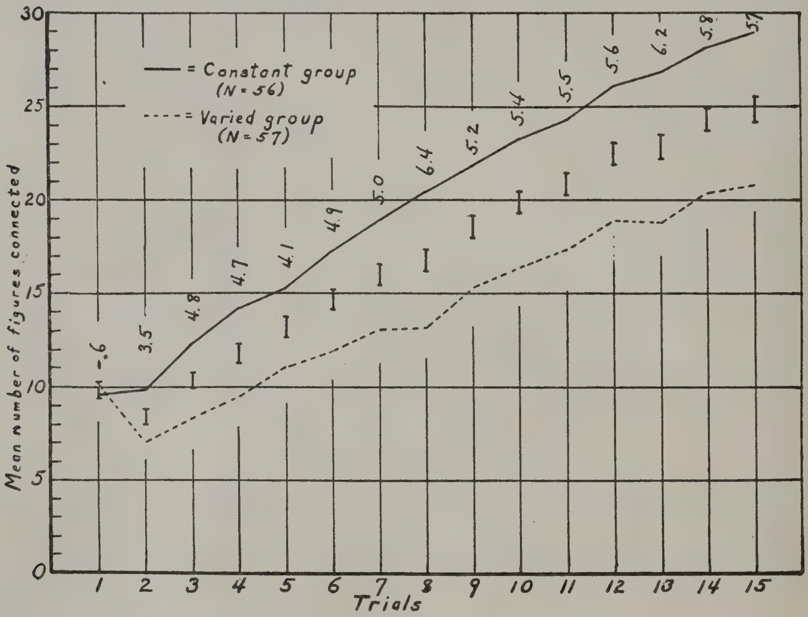


FIGURE 6

RESULTS OF THE NUMBER MAZE EXPERIMENT

The vertical bars indicate $S.E._{diffs}$. The numbers above the curves indicate $\frac{M_c - M_v}{S.E._{diff}}$. Two minutes were allowed for Trial 1, 1′ for each other trial.

The varied sheets in this experiment all had the same shape of path to be traced—i.e., the successively higher figures were in the same relative positions—but each sheet was different from any other in that all of the numbers had been increased or decreased by a certain definite sum. The maze shown in Figure 5, for instance, starts with 214. The 14 other sheets employed started respectively with 200, 207, 211, 212, 213, 215, 216, 219, 223, 228, 231, 240 and 256; and all of the other figures on the sheets were changed correspondingly. Thus, on the sheet starting with 207, every figure on the sheet was 7 smaller than the corresponding figure on the sheet starting with 214. The order in which the different varied subjects were presented with these different sheets was determined by chance. With the constant subjects, approximately even numbers of subjects utilized the sheets starting with 200, 207, 211, etc.

Results. The results with the number maze are presented in Figure 6 and Table 3. The constant group learned at a decidedly more rapid rate. It is true, of course, that the varied subjects virtually quadrupled their score in the 15 trials (considering that 2′

TABLE 3

Results of the Number Maze Experiment: Mean Number of Figures Connected by the Constant and the Varied Subjects

	Constant group (*N*=56)			Varied group (*N*=57)			$\frac{M_c—M_v}{S.E._{diff.}}$
Trial	Mean score	*S.D.*	$S.E._M$	Mean score	*S.D.*	$S.E._M$	
1	9.6	4.3	.58	10.1	5.0	.66	–.57
2	9.8	4.2	.57	7.0	4.2	.55	3.49
3	12.4	4.6	.61	8.4	4.3	.57	4.79
4	14.2	5.4	.73	9.5	5.0	.66	4.74
5	15.4	5.0	.66	11.1	5.3	.70	4.09
6	17.4	6.0	.80	12.0	5.8	.77	4.86
7	19.0	5.9	.79	13.1	6.4	.85	5.05
8	20.5	5.9	.79	13.1	6.1	.81	6.44
9	21.9	6.8	.91	15.4	6.4	.85	5.24
10	23.3	6.3	.84	16.5	7.1	.94	5.39
11	24.3	6.9	.93	17.4	6.3	.84	5.52
12	26.0	6.6	.89	19.0	6.9	.91	5.58
13	26.9	7.0	.94	18.8	7.0	.93	6.18
14	28.1	7.4	.99	20.5	6.4	.85	5.85
15	29.0	7.6	1.02	20.9	7.5	1.00	5.66

were allowed for the first trial and 1′ for each other trial), and this increase of score demonstrates that to some extent these different sheets were equivalent stimuli. However, the more rapid learning of the constant subjects indicates that the varied sheets were by no means fully equivalent stimuli. Why not? Probably one reason was that, as determined from the reports of the two groups, the varied group did not realize quite as quickly as did the constant group that the same pattern of path was being used on trial after trial. Another factor that was probably still more important, however, is that, just as with the pencil maze, the habits developed at such a problem as this are not merely habits of turning in such and such a direction at different points, but rather are perceptual habits which facilitate the recognition and visual exploration of the surface exposed. In the number maze the subject does not utilize merely the numbers of the correct path to guide himself, but also the figures which surround and give the background for these true-path figures. Hence, when all of the figures on the sheet are changed, even though the scheme of the maze is kept *logically* the same, some of the cues are removed by which the subjects learn to guide themselves, and, consequently, the variation decreases the speed of learning.[4]

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[4] It may be well to stress that we do not interpret the learning in this case as having been dependent merely upon simple perceptual habits. It was found that no appreciable progress in learning the maze was made by the few varied subjects who did not come to realize until late in the course of the 15 trials (or until they were told afterwards) that the pattern had been constant. Some of these subjects, even on the 10th trial or later, would connect only one or two figures. From these cases it seems certain that most of the subjects would not have learned as rapidly if they had not formulated to themselves the statement that the same pattern existed on all of the sheets. In the second place, it was found that almost all subjects developed direction habits for whatever portion of the maze they traversed. Immediately after the 15th trial each subject was given a sheet on which three zeroes replaced each of the 3-place figures on the regular sheet, and the request was made that the subjects trace the path which they had found on the other sheets. Most subjects could roughly duplicate the portion of the path which they had traversed, although sometimes whole angles were omitted, and generally the turning points were removed one to three places from the correct spots. This reaction indicates that the subjects had habits which enabled them to search, in almost every case, in approximately the correct position for the next larger number. The fact that this zero path was not traced exactly proves, however, that these turning habits alone could not lead them correctly, but that perceptual habits for the different regions were also required. It was primarily the disturbance of these later habits which slowed the learning of the varied subjects.

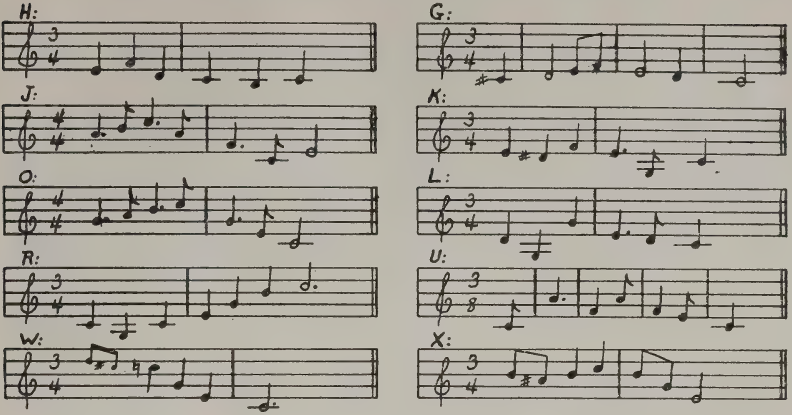

FIGURE 7

The Melodies Used in the Melody Experiment

All melodies are shown in the key of C, as used in Trial 18. The letters above the various bars are the letters which the subjects had to learn to associate with these various melodies.

The Melody Experiment

This experiment utilized the simple piano melodies shown in Figure 7. With any given group of subjects five of these melodies (either the left five or the right five in Figure 7) were always played in the same key and pitch (that indicated in Figure 7), and the other five melodies were given in a different pitch or key on the different trials. The 14 variations employed with each varied melody consisted of 7 variations that raised the pitch by 1 to 7 half-tones and 7 that lowered the pitch by the same amounts. The order of presentation of the variations on successive trials for any given melody was a chance order, except that on the 18th trial all of the melodies were presented as in Figure 7. To equate for possible differences in the easiness of the melodies, approximately half of the subjects had, as varied melodies, the melodies that were constant with the other subjects.[5]

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[5] Actually the two groups were not exactly equal in number, one consisting of 51 subjects and the other of 57. This, of course, would not have mattered if the two groups of melodies had been equally easy to learn. But the one set of melodies (H, J, O, R, and W) proved to be so much easier than the other set that there were about a third more of correct associations to them than to the more difficult five melodies. Hence, in calculating the mean scores and the differences between the rate of learning

TABLE 4

RESULTS OF THE MELODY EXPERIMENT: MEAN NUMBER OF CORRECT ASSOCIATIONS TO THE CONSTANT AND VARIED MELODIES RESPECTIVELY

Fifty-one subjects served with the melodies H, J, O, R, and W varied and the other melodies constant; 57 other subjects served with the melodies G, K, L, U, and X varied and the other melodies constant. The mean score for the varied material consists of the mean of the mean score of the 51 subjects and the mean score of the 57 subjects on the varied material; the mean score for the constant material was similarly secured. The *S.D.*, $S.E._M$, and $r_{c.v}$ in every case were figured from the total group of 108 subjects in the ordinary fashion, employing the unweighted means.

	Constant material			Varied material				
Trial	Mean score	*S.D.*	$S.E._M$	Mean score	*S.D.*	$S.E._M$	$r_{c.v}$	$\frac{M_c - M_v}{S.E._{diff.}}$
3	.68	.84	.081	.78	.96	.092	.00	–.81
6	1.34	1.10	.106	1.18	.98	.094	.08	1.18
9	1.59	1.23	.118	1.50	1.10	.106	.11	.60
12	1.68	1.10	.106	1.38	1.21	.116	.20	2.13
15	2.05	1.28	.123	1.86	1.24	.119	.60	1.74
18	2.19	1.38	.133	2.28	1.40	.135	.51	–.68
21	2.37	1.32	.127	2.27	1.44	.139	.47	.73
All trials	11.92	5.73	.551	11.25	5.54	.533	.56	1.31

Note: If the unweighted means had been used throughout, the values for $\frac{M_c - M_v}{S.E._{diff.}}$ in the above table would have been respectively —.57, 1.33, .80, 2.34, 2.02, —.60, .80, and 1.62—values only slightly different from the above.

To measure the degree of learning in this experiment the technique of paired associates was used. On Trials 1 and 2 the experimenter would pronounce one or another of the letters shown in Figure 7, then the melody associated with that letter would be played; then after an interval of 3″ another letter would be pronounced, etc. On every third trial the melodies were played without being named

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of the varied and the constant material, the mean scores were calculated first for the 51 subjects for the varied and constant material respectively and then similarly for the 57 subjects, and then the means of the means of the two groups were found, to find what the tendency was in the group of 108 subjects as a whole. By this procedure we get a truer picture of what the results of our conditions tend to be—we come closer to the result than would have been found if the number of subjects used with the first five melodies varied had equalled the number with the second five varied, as should have been the case.

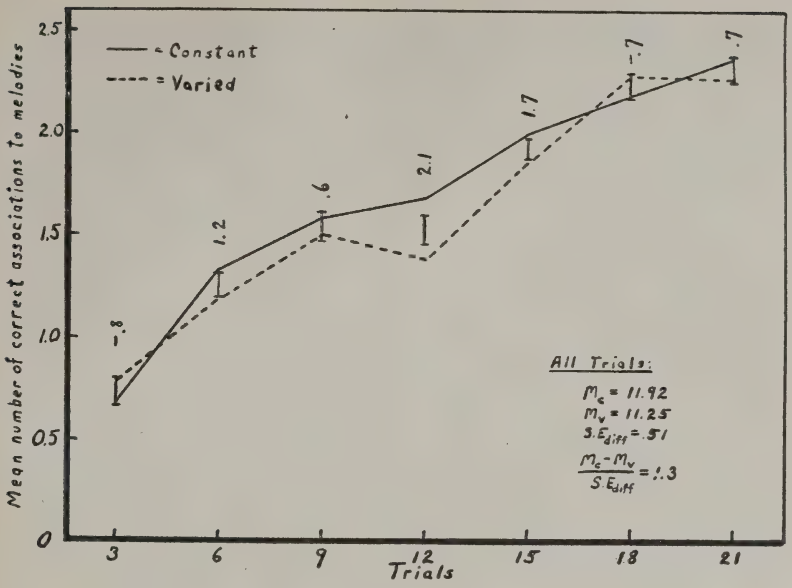

FIGURE 8

Results of the Melody Experiment

The same subjects ($N = 108$) learned both the constant and the varied melodies. The vertical bars indicate $S.E._{diffs}$. The numbers above the curves indicate $\frac{M_c - M_v}{S.E._{diff}}$.

(with intervals of 5″ between successive melodies), and the subjects recorded what letters seemed to them to be demanded. The order of presentation of the 10 melodies was, of course, varied from trial to trial so that there could be no learning on the basis of serial position. Inasmuch as there were but 15 variations of each melody to be distributed through 21 trials, six variations of each melody had to be employed twice in the 21 trials, but no variations were used more frequently than that. As in the pencil maze experiments and the number maze experiments, no mention was made to the subjects of the fact that the material was to be varied in any way on different trials. It is perhaps worth noting that about a fourth of the subjects did not realize that any variations in pitch were being employed.

Results. As in shown in Figure 8 and Table 4, the melody experiment provides further evidence that changing the absolute qualities of stimulation and leaving the internal pattern unchanged does not affect, favorably or unfavorably, the rate of learning. There were no reliable group differences on any trial or on the total score, despite the large number of subjects used and despite the fact that the formula involving the correlations between the scores on constant and varied melodies was used to calculate the $S.E._{diff.}$ in each case.

The degree of superiority which the constant material does show is probably explained by the fact that this experiment is fundamentally a discrimination experiment rather than one in which the learning was measured by the ability of the subjects to reproduce in some way the different melodies. The differences in pitch were frequently clearly noticeable, and, consequently, the subjects could to some extent discriminate on the basis of pitch rather than merely on the basis of the melodies as such. Many subjects reported that they had tried, particularly at first, to learn on this basis of pitch. Such attempts, of course, favored the constant melodies. In view of this situation, the trial which is of greatest significance is the 18th trial, because only on this trial were the varied melodies given in the standard pitch (shown in Figure 7) used throughout with the constant melodies. This procedure caused the 18th trial to be the one on which the differences in pitch and the possibilities of differentiating between the melodies on this basis were reduced to a minimum. And, on this 18th trial the varied melodies were correctly identified slightly more often than the constant melodies. Taking the results of the melody experiment as a whole we can say with considerable certainty that when melodies are presented in such varied fashion as here employed the melodies as such will be learned quite as rapidly when varied as when always presented in the same pitch and key.

Let us now consider the question as to whether this melody experiment is free from the defect explained in the section above on "General Methodological Principles." The question is as to whether, with this material, the subjects could utilize any intermediate responses provided by habit which could give a constant stimulus for the association response. The subjects reported several different methods of learning. Some tried to learn merely by relating the melodies directly to the letters given with them. Insofar as this style of learning was used there is, of course, no question about the suitability of this melody material. Other subjects tried to learn by humming the melodies to themselves and linking the letters with this.

Even with these subjects, however, the situation is still satisfactory, because the subjects naturally tended to hum each melody in the key and pitch in which it had just been played; and consequently, even though they might have been essentially connecting the letters to their hummings, the fact would still remain that they were connecting the final association to varying stimuli. Still other subjects tried to learn by building up visualizations of the melodies, either as printed notes or (more frequently) in some rough schematic arrangement. In these cases, even though we may think of the visualizations as having provided a fairly stable intermediate basis for the final response, the fact would still remain that this intermediate link was not made possible by past habit development. Regardless of whether subjects are learning a constant response "K," "W," etc., to varying melodies, or whether they are developing a constant intermediate visualization process to which the naming response is secondarily linked, in either case the situation is fundamentally the same—the subjects are learning to make a more or less constant response to a varying stimulus. And, as the melody experiment indicates, the learning proceeds as rapidly under this condition as when the subjects are learning to make their constant response to a constant stimulus.

THE RHYTHM EXPERIMENTS

The procedure of the two rhythm experiments was very similar to that of the melody experiment, and consequently need not be described in detail. Figure 9 indicates diagrammatically the rhythms employed and the words presented with them by the technique of paired associates. The apparatus for producing the rhythms included a kymograph, a multiple electric switch, a battery and wiring connections, and 8 buzzers and telegraph keys so adjusted as to yield quite distinctly different qualities of sound. The paper on the kymograph drum was perforated with holes so spaced that when the drum was revolved against a wire brush, one or another of the rhythms would be sounded as a result of the electrical circuits established. The time interval from the start to finish of each rhythm was the same for all rhythms—about 4″. The variations of the material in this experiment were secured by connecting the kymograph with different sounders so that the varied rhythms were presented in quite different qualities of sound on the different trials.

The features of procedure in which the rhythm experiments dif-

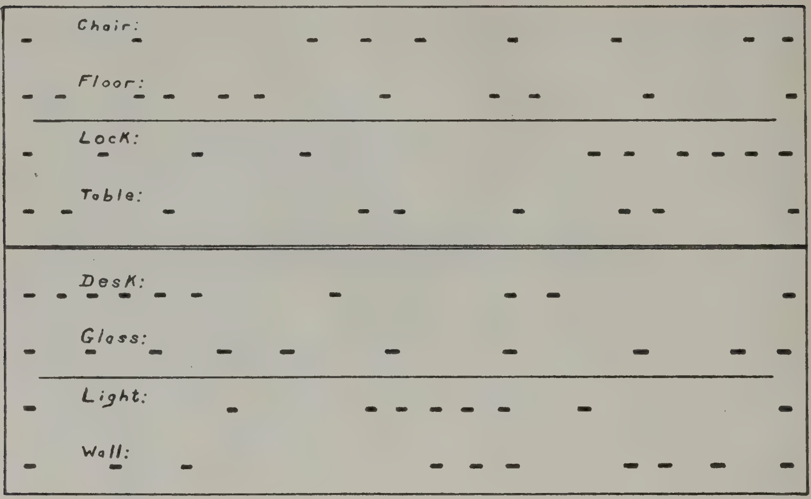

FIGURE 9

Diagram of the Rhythms Used in the Rhythm Experiment

The short dashes indicate the relative duration of the sounds in the various rhythms. The words above the various rhythms are the words which the subjects had to learn to associate with the various rhythms.

fered from the melody experiment were: (1) test trials were given only every fourth trial; (2) the subjects were warned that the rhythms might be given with different sounds and that it would prove confusing to them if they tried to identify the different rhythms on the basis of the quality of sound used; (3) the material (words in this case) which the subjects had to learn to associate with the rhythms was mimeographed on the same sheet which each subject had with the instructions and cells for entering associations also mimeographed on it. This listing of the response words was done because some preliminary work proved that the task of learning these rhythms was so difficult as to make desirable every measure that would eliminate any irrelevant difficulties in the learning situation.

The four upper rhythms of Figure 9 were varied with about half of the subjects in each experiment, and the other four rhythms with the other subjects.[6]

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[6] In the rhythm experiments this division was more nearly exact than it had been in the melody experiment, and furthermore, it was shown that these two groups of rhythms were about equal in difficulty. Consequently, the results are presented in terms of the simple mean scores for the varied and constant material respectively.

As between the first and the second rhythm experiment, the difference was solely this: In the first rhythm experiment each of the constant rhythms was given with a different sounder, whereas in the second rhythm experiment all of the constant rhythms were presented with the same sounder with any given set of subjects. A different sounder was used with each constant rhythm in the first experiment because it was thought that some sounders would present the rhythms more favorably than other sounders. All of the sounders, of course, had to be used with the varied rhythms, and it was thought that conditions would be better equated if all of the sounders were likewise used with the constant rhythms. The results of this first experiment, however, led us to suspect that rather than equating conditions, this use of particular sounders with each constant rhythm was helping the subjects to identify rhythms on the basis of quality of sound. So, inasmuch as we were primarily interested in the question as to whether the rhythms as such could be learned as rapidly when varied as when constant, another experiment was conducted in which absolute differentiating cues were minimized by giving all four constant rhythms with the same sounder. Three sets of subjects were employed, and with each set a different one of the three most distinct sounders was used to produce the constant rhythms.

Results. The results from the first rhythm experiment are shown in Figure 10 and Table 5. Inasmuch as in this experiment, as noted above, the subjects had an almost optimal basis for identifying the

TABLE 5

Results of the Rhythm Experiment in Which a Different Sounder Was Used with Each of the Constant Rhythms: Mean Number of Correct Associations to the Varied and Constant Rhythms Respectively

The same subjects ($N=66$) served with both the constant and the varied rhythms.

	Constant material			Varied material				
Trial	Mean score	*S.D.*	$S.E._M$	Mean score	*S.D.*	$S.E._M$	$r_{c.v}$	$\frac{M_c - M_v}{S.E._{diff.}}$
4	.82	.85	.10	.64	.76	.09	.17	1.42
8	1.11	.88	.11	1.05	1.04	.13	.45	.48
12	1.48	1.02	.13	1.12	1.12	.14	.39	2.46
16	1.78	1.24	.15	1.58	1.22	.15	.50	1.32
20	2.12	1.28	.16	1.60	1.19	.15	.53	3.51
All trials	7.27	3.39	.42	5.99	3.75	.46	.69	3.58

different rhythms on the basis of the quality of sound, and inasmuch as the rhythms as such were very difficult to learn, one might have expected that the constant rhythms would be much more readily learned. Such was certainly the case.

The results of the second rhythm experiment are shown in Figure 11 and Table 6. In this experiment, as noted above, all of the con-

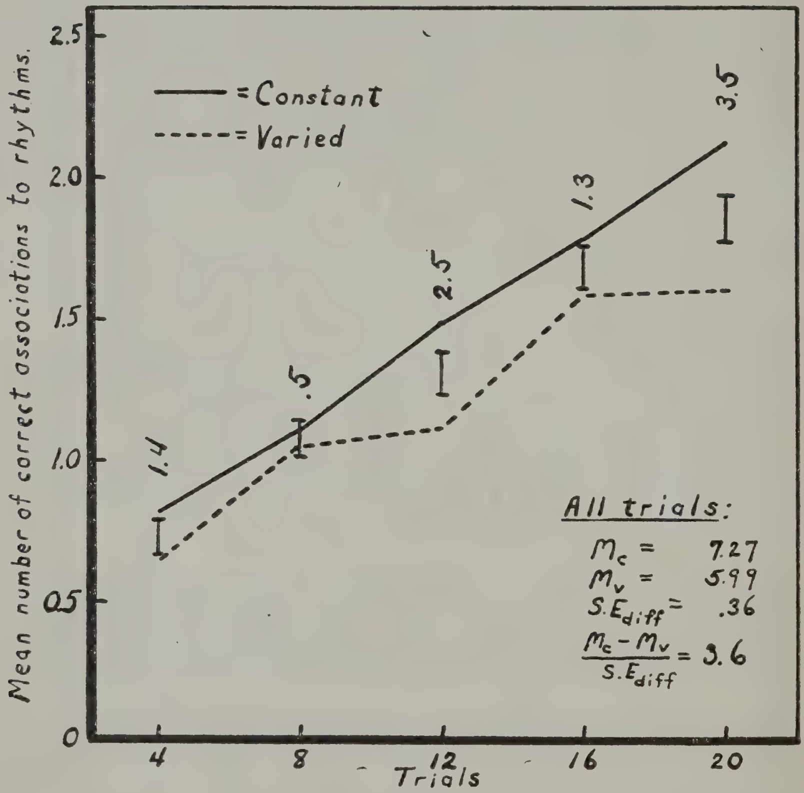

FIGURE 10

Results of the Rhythm Experiment in Which a Different Sounder Was Used with Each of the Constant Rhythms

The same subjects ($N = 66$) served with both the constant and the varied rhythms. The vertical bars indicate $S.E._{diffs}$. The numbers above the curves indicate $\frac{M_c—M_v}{S.E._{diff}}$.

stant rhythms were given with the same sounder; so in this experiment the different constant rhythms could not be identified on the basis of the quality of the sound used, as, of course, could not be done with the varied rhythms. In consequence, the varied material was learned as rapidly or even slightly more rapidly than the constant material. It is interesting, too, to note that the learning curves in this second rhythm experiment virtually duplicate the learning curve for the varied material in the first rhythm experiment, indicating more certainly the reliability of the scores in the two experiments.

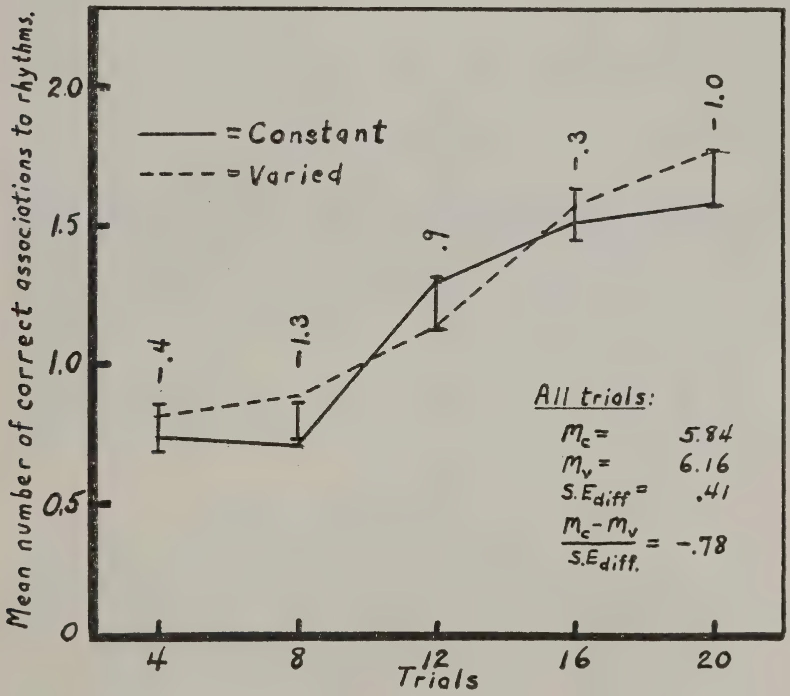

FIGURE 11

Results of the Rhythm Experiment in Which All Constant Rhythms Were Given With the Same Sounder

The same subjects ($N = 43$) served with both the constant and the varied rhythms. The vertical bars indicate $S.E._{diffs.}$. The numbers above the curves indicate $\frac{M_c - M_v}{S.E._{diff.}}$.

TABLE 6

RESULTS OF THE RHYTHM EXPERIMENT IN WHICH ALL CONSTANT RHYTHMS WERE GIVEN WITH THE SAME SOUNDER: MEAN NUMBER OF CORRECT ASSOCIATIONS TO THE VARIED AND CONSTANT RHYTHMS RESPECTIVELY

The same subjects ($N=43$) served with both the constant and the varied rhythms.

	Constant material			Varied materials				
Trial	Mean score	$S.D.$	$S.E._M$	Mean score	$S.D.$	$S.E._M$	$r_{c.v}$	$\frac{M_c - M_v}{S.E._{diff.}}$
4	.74	.94	.14	.81	.87	.13	.34	–.44
8	.70	.88	.13	.88	.94	.14	.52	–1.32
12	1.30	1.13	.17	1.14	1.09	.17	.40	.86
16	1.51	1.15	.18	1.56	1.08	.16	.43	–.27
20	1.58	1.47	.22	1.77	1.25	.19	.58	–.98
All trials	5.84	3.60	.55	6.16	3.93	.60	.75	–.78

These two rhythm experiments, taken together, not only indicate that rhythms as such will be learned as rapidly when presented in different qualities of sound as when always presented in the same sound, but also quite clearly support the analysis given above, in the discussion of the melody experiment, of the influence of the discrimination form of experiment.

As regards the question as to whether the rhythm material satisfies the demands of our experimental problem, the considerations involved are analogous to those explained above for the melody experiment, and need not be repeated here.

THEORETICAL SIGNIFICANCE OF RESULTS

In view of the elaboration at the beginning of this article of the possible significance of such a study as this, only relatively brief interpretative comments are needed at this point. This study has served to prove that the absolute qualities of stimuli can be varied over a considerable range without destroying the equivalence of these stimuli, if the internal patterns of the stimuli are kept constant. This study further indicates that the mechanisms producing equivalence are characteristic not merely of the developed habit, but of the earlier stages of learning as well. Still further, since the stimuli were modified markedly enough so that, if a specific-path theory of learning were true, widely different neural paths would have been involved in the different trials with any of the varied stimuli, we have further evidence that the physiological basis of learning is not a reduction of resistance along specific pathways, but is some change which may be best described as a dynamically organized condition in the nervous system. Moreover, since the rate of learning with varied material was not different from that with constant material, it would seem that there are probably no different mechanisms involved when the material is varied than when it is constant, and that, consequently, the neural mechanisms of all forms of learning are probably of this dynamically organized sort.

One last question that might be raised is that of the relation of the principle of equivalence of stimulation to the problem of transfer of training. It might seem at first glance that what has been done in this experiment is merely to test an old phenomenon under a new label. Rather than that, however, we would suggest this interpretation: The expression "transfer of training" is a general term that refers to all of the different ways in which learning in one particular situation affects learning in other situations. By such experiments as this, on the other hand, we may hope to analyze the possibly complex assortment of processes that collectively we have traditionally termed "transfer of training," and lay the foundations for an answer to the question of why in one situation transfer of training is virtually complete, in other situations only barely perceptible, etc. Or, in other words, the principle of equivalence of stimulation might be thought of as one specific phase or aspect of the broader, more vague concept of transfer of training.

Summary

The present experiments were designed to give a further test of the question as to whether the physiological basis of learning is the reduction of resistance along definite neural paths or whether learning is dependent upon neural changes which make the stimuli effective because of the pattern or organization of the neural activity set up. In contrast with previous studies of equivalent stimulation, almost all of which have tested for equivalence at the conclusion of training, the stimuli used were varied throughout the course of training (i.e., except as regards their internal pattern), the object being to determine whether the rate of learning with such varied material would equal the rate of learning with material always presented in a constant fashion.

Four different types of learning material were used, and a total of

510 subjects were employed. The different experiments involved the use of the following materials: (1) a complex pencil maze, variations of which were secured by having the maze printed in different scales; (2) a complex number maze, variations of which were secured by changing by certain sums all of the figures on the sheet; (3) a series of 10 simple melodies, variations of which were secured by changing the key or pitch; and (4) a series of 8 rhythms, variations of which were secured by presenting the rhythms in quite different qualities of sound.

The results of the experiments show that the rate of learning under the condition of varied stimulation was roughly the same as under the condition of constant stimulation in the experiments with the pencil maze, melodies, and rhythms. There were no reliable group differences in any of these experiments. On the number maze the constant subjects learned at a much more rapid rate, but an analysis of the learning material of this experiment shows that, unlike the other materials, it did not present in a very complete degree the requirements for sensory equivalence, even though the variations had left the different sheets logically equivalent.

The group of experiments, then, demonstrate that when stimuli are varied, at least within certain quite wide limits, as regards their absolute characteristics, this will not result in slowing up the learning process if the internal organization of the stimuli is kept unchanged. The results are interpreted as indicating that the phenomenon of equivalence of stimulation is integral to the learning process itself, and that, consequently, learning theory must picture the physiological basis of learning as being changes which function as dynamically organized neural patterns.

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UNE ÉTUDE EXPÉRIMENTALE DE LA STIMULATION ÉQUIVALENTE DANS L'APPRENTISSAGE HUMAIN

(Résumé)

On a fait cette étude dans le but d'obtenir d'autres données pour déterminer si la base physiologique de l'apprentissage est la réduction de la résistance dans des sentiers nerveux définis ou de tels changements que ceux suggérés par les psychologues Gestalt. Pour répondre à cette question, on a employé quatre types différents de matière à apprendre pour découvrir si la vitesse de l'apprentissage serait approximativement la même quand on a présenté la matière à apprendre de la même manière dans tous les essais que quand on a changé les caractéristiques absolues (mais non l'ordre interne) des différents stimuli dans chaque essai. La matière à apprendre des différentes expériences a été la suivante: un labyrinthe complexe à crayon, un labyrinthe de nombre, une série de simples mélodies pour piano, et une série de rythmes. Un total de 510 étudiants universitaires ont servi de sujets. Le résultat d'un examen quantitatif soigneux des données expérimentales montre que dans les conditions de variation spécifiées ci-dessus la vitesse de l'apprentissage ne paraît pas être influencée par les changements de stimulation. Cela indique que les bases nerveuses de l'apprentissage sont des processus organisés d'une façon dynamique.

Leeper et Leeper

EINE EXPERIMENTELLE UNTERSUCHUNG DER ÄQUIVALENTEN REIZUNG BEI MENSCHLICHEN LERNEN

(Referat)

Diese Untersuchung wurde ausgeführt in der Absicht weitere Tatsachen zu sammeln über die Frage, ab die Physiologie des Lernens auf Verminderung des Widerstands längs bestimmter Nervenbahnen auf Veränderungen ähnlich den von Gestaltpsychologen vorgeschlagenen beruhe. Um diese Frage zu beantworten, wurde Gebrauch gemacht von vier verschiedenen Arten von Lernstoff, in der Absicht, zu ermitteln, ob die Lernschnelligkeit ungefähr die selbe sein würde, wenn die Lernstoffe in jedem Versuch immer wieder auf die gleiche Weise dargeboten wurden, wie wenn die absoluten Eigenschaften (aber nicht die innere Anordnung) der verschiedenen Reize von Versuch zu Versuch abgeändert wurden. Die Lernstoffe der verschiedenen Versuch waren folgende: ein komplizierter Griffellabyrinth, ein Nummerlabyrinth, eine Reihe einfacher Klaviermelodien, und eine Reihe von Rhythmen. Es dienten als Versuchspersonen im Ganzen 510 Studenten. Die Ergebnisse einer sorgfältigen quantitativen Untersuchung der experimentellen Befunde beweisen, dass unter den obenbeschriebenen Verhältnissen des Wechsels (variation) die Schnelligkeit des Lernens durch die Abänderungen des Reizes anscheinend nicht beeinflusst wird. Hierdurch wird darauf hingewiesen, dass die neurologische Grundlagen des Lernens dynamisch organisierte Vorgänge sind.

Leeper und Leeper

PART I: THE EFFECT OF VERBAL INSTRUCTIONS UPON STYLUS MAZE LEARNING*[1]

From the Department of Psychology of the University of Vermont

J. F. LAMBERT AND P. H. EWERT

INTRODUCTION

In the present study we are concerned with the "set" following minimal, standard, *maximal verbal instructions and maximal verbal instructions* plus visual exposure in overt (maze activity) behavior.[2] Our simplest (minimal) instructions, "Slide your stylus along in the grooves until the experimenter says 'Stop,' " are comparable to the type of motives used in animal experimentation in that the subject is forced to formulate his *Aufgabe* as he explores the problem. Such an *Aufgabe* is never definitely formulated and fixed until the subject has successfully traversed the maze or solved the problem often enough to establish in him a definite orientation to the goal, to which he then reacts more or less mechanically. Maximal verbal instructions are such as will lead to a correct solution of the problem in the first trial, provided that they are accurately carried out. The standard instructions are such as are ordinarily used in stylus maze experiments.

If, as Hunter (15), Watson (47), Weiss (48), and others have asserted, language may be regarded as a substitute for objects and for manipulatory acts, we should be justified in expecting that the learning period would be shortened in proportion as the verbal substitutes are furnished the subjects in the instructions.

A number of different kinds of "set" have been recognized and studied. Among them are the "social" set, as opposed to the

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[1] This research was conducted at the University of Vermont from October 15, 1929 to June 1, 1930.

[2] A short while ago, after the experimental part of this study was completed and the results had been presented to the University of Vermont Library in thesis form, there appeared a paper by L. W. Gellermann (11*a*) in which 'minimal instructions" were given to human subjects learning a maze. This study thus remains unique in contrasting "minimal" and "maximal" verbal instructions with "standard" instructions.

"solitary" (1, 2, 11); sets induced by competition (41, 49, 50), by encouragement and discouragement (13), by praise and reproof (12), by suggestion (35) and various emotional states (8), by punishment (9, 34), and by rewards and incentives (7, 10, 16, 17, 18, 19, 22, 26, 27, 36, 51). Another group included the sets brought about by knowledge of time of recall (29, 33), by knowledge of the results of one's previous efforts (5, 23, 39, 45), and without knowledge of results (39); by knowledge of the amount of work to be done, or the amount of time allowed for work—"quantitative" sets (6, 30). Other sets are those determined by preference and value of work, and the effort required to master it (3); the general attitude, as opposed to the specific (4); the set ensuing from engaging in a particular task, as it affects the change to another kind of task (21); sets resulting from positive, as opposed to negative, instruction (42); and the modification of reflexes by voluntarily induced sets (31).

An examination of these investigations shows: (*a*) that in few, if any, cases are the groups equated except by chance; (*b*) that in only one case (40) was performance related to intelligence, as determined by standard tests; (*c*) that in no case did all groups and each subject serve in the control as well as in the training series. Our study is unique in the foregoing respects.

The data of this investigation shed light upon the following problems: (*a*) what effect do verbal instructions have upon the nature and efficacy of stylus maze learning? (*b*) What is their effect upon individual and group variability in this type of learning? (*c*) What bearing have they upon the correlation of intelligence test performance and improvement in this type of activity?

The stylus maze was chosen to typify overt behavior because (*a*) it represents a type of activity which has undergone much investigation in other respects; (*b*) the apparatus is quite simple; (*c*) it is fairly easy to obtain naïve subjects; (*d*) it lends itself readily to quantitative treatment; (*e*) the learning process is to a comparatively large extent objectively observable.

The Subjects

The 40 subjects used in these experiments were all undergraduates at the University of Vermont. It was essential that all be naïve; hence it was necessary to use mostly members of the lower classes. The subjects were equated by means of intelligence test rank and

TABLE 1

THE SUBJECTS

Subject	Int. decile	Class	Subject	Int. decile	Class
	Group 1			*Group 2*	
1A1	1	1931	2A1	1	1931
1B2	2	1932	2B2	2	1933
1C3	3	1933	2C3	3	1933
1D4	4	1931	2D4	4	1933
1E4	4	1930	2E4	4	1931
1F5	5	1933	2F5	5	1932
1G6	6	1933	2G6	6	1933
1H7	7	1932	2H7	7	1933
1I8	8	1933	2I8	8	1933
1J8	8	1933	2J8	8	1930
	Group 3			*Group 4*	
3A1	1	1930	4A1	1	1933
3B2	2	1933	4B2	2	1930
3C3	3	1933	4C3	3	1931
3D4	4	1930	4D4	4	1932
3E4	4	1932	4E4	4	1933
3F5	5	1933	4F5	5	1932
3G6	6	1932	4G5	5	1932
3H6	6	1933	4H6	6	1933
3I8	8	1933	4I8	8	1933
3J9	9	1931	4J10	10	1933
Mean intelligence decile, each group			4.8		
Median intelligence decile, each group			4.5		

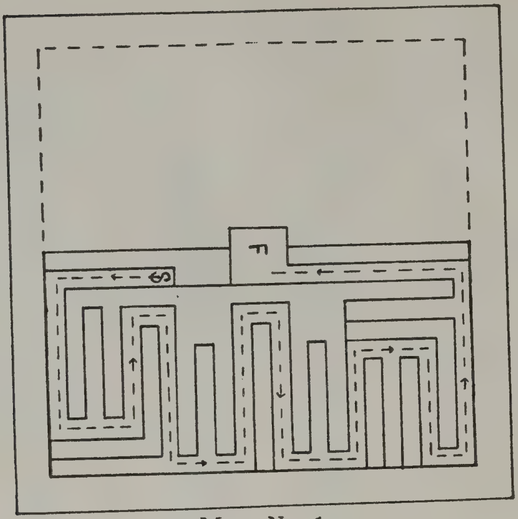
college class. As different forms of the Thurstone test are given at the University each year, it was impossible to compare the raw scores of members of different classes. Instead, therefore, their decile rankings were used. The word "intelligence," wherever used in this paper, refers to the results of these tests. Table 1 shows the status of the different subjects.

There was approximately the same number of each class in each group, and the same number of each sex.

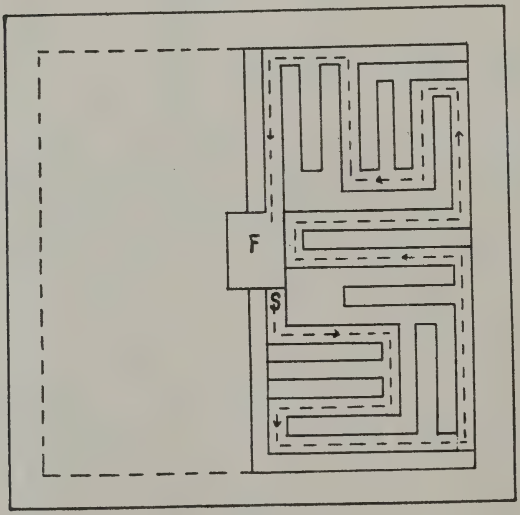
To facilitate tabulation, and to withhold the identity of the subjects, each was designated as indicated above. In each case the first digit refers to the group in which the subject was placed; the letter to the subject himself, within the group; and the last digit to the subject's intelligence decile. Thus, 3F5 means Subject F in Group 3, whose intelligence decile is 5.

PLAN OF EXPERIMENTATION

The experiments were conducted individually. Most of the work was done in the evening. The subjects were assigned to the same



Maze No. 1



Maze No. 2

FIGURE 1
THE MAZES

S—start; *F*—finish; scale—$\frac{1}{1.4}$

group in each experiment, but were used in random order.

A control maze and a training maze were presented at the same appointment. The training maze was learned before the control maze, because any familiarity with the maze situation would have precluded the possibility of obtaining any significant results from the work of Group 1 under its abridged instructions. Of course, there is opportunity under these conditions for a transfer of training from the training maze to the control maze. Results seem to indicate, however, that what transfer did take place was that of general familiarity with the maze situation rather than any specific pattern transfer. Furthermore, the fact that all groups were subjected to the same routine should equalize any disturbing element of that kind.

THE EXPERIMENT

Apparatus. The maze used in this experiment was the Pechstein adjustable maze, which is constructed of brass on a wooden base.

The plugs were adjusted for our purposes so that one half of the maze could be used as a control for the other half. (See Figure 1.) One half will be referred to as Maze 1 and the other half as Maze 2. The length of the true path of Maze 1 was 28½ inches, while that of Maze 2 (control) was 29 inches. To obscure the maze from *S*'s vision it was placed in a large box, of such proportions as to allow freedom of movement of *S*'s hand. Two opposite sides of the box were left open, and on the side toward *S* a black cloth was tacked, which was allowed to fall down over and around *S*'s arm. The other side was left without any drapery, so that *E* could follow the progress of *S*'s stylus. Another black cloth was thrown over the top and remaining sides of the box. All experiments were done under artificial lighting, with *S* facing the light so as to make the maze more readily visible to *E*.

Procedure. The instructions for the different groups were as follows:

Group 1:

> "Slide your stylus along in the grooves until the experimenter says 'Stop.' Keep the stylus in the grooves and do not touch any other part of the apparatus with your hand."

Group 2:

> "This experiment is a problem in maze learning. You are to slide the stylus along in the grooves in an attempt to find a path which will lead you out of the maze. Keep the stylus in

> the grooves and do not touch the maze with your hand. Try both to reach the goal as quickly as possible and to learn to avoid wrong turns. You are to continue the learning process until you have made two errorless trials in succession. Start when the experimenter says 'Go' and keep the stylus going until he says 'Stop.' "

Group 3: The instructions given to Group 2 plus the following:

> "This maze consists of a series of alleys arranged in perpendicular sequence according to a definite system. Try to discover what this system is, so that you may learn the correct path more quickly."

Group 4: The instructions given to Group 2 plus the following:

> "This maze consists of a series of alleys arranged in perpendicular sequence according to a definite system. You will reach the goal by the shortest path if you move the stylus in the following manner: (*a*) When you cannot go toward one side or the other, or when you have gone as far as you can toward one side, move the stylus directly toward or away from yourself as far as it will go. All the moves of this kind are away, except the first and last, which are toward you. (*b*) The lateral moves are in alternate sequence, first right, then left, and so on."

No further instructions were given, but questions asked by *S* were answered, provided they were concerned only with the instructions already given. No information was imparted concerning the purpose of the experiment or the nature of the maze.

Retracing or entrance into a blind alley were considered errors. In retracing, the interval between turns was the unit of error. After every tenth trial, a rest of two minutes was given. During this period *E* carried on conversation with *S*, but care was taken to make no reference to the experiment itself.

Spontaneous remarks made by *S* during the learning period were noted, but all questioning was left until the end, to prevent the giving of unintentional cues.

The instructions and procedure for Maze 2 (control) were the same as those which Group 2 received with Maze 1.

Results. The comparative results of the four groups in Maze 1 are shown in Table 2. In the number of trials required to learn the maze, the number of errors, and the learning time, there is a difference corresponding in general to the type of instructions received. Group

TABLE 2

COMPARATIVE GROUP RECORDS: MAZE 1

Group	Av. trials to learn	Av. total errors	Av. time to learn	Av. final time
1	11.2	50.0	6.15 min.	9.6 sec.
2	10.1	53.7	5.48	10.2
3	8.2	28.2	2.96	11.1
4	6.7	22.2	2.15	9.6

4 has only about 60% as many trials as Group 1. The only exception is in the case of Group 2, which made more errors than Group 1. The difference in this case, however, is too small to be of any great significance.

In the control maze, Table 3, however, there is very little difference between the groups, the greatest difference being in the number of errors. Furthermore, there is no consistent trend of differences in the various quantitative aspects to indicate that any group was noticeably superior to any other. This would seem to show that the group differences in reactions to Maze 1 must be due to the change in instructions.

In errors, the groups are aligned in Maze 1 in order of the amount of instructions received, except for Group 2, which has an unduly large number. In the control maze there is also an irregularity, Group 3 having the least, and Group 1 the most errors, there being a somewhat greater difference than we would expect, nearly 58% of the former. In both mazes, Groups 3 and 4 made fewer errors than Groups 1 and 2, the percentage of difference being considerably greater in Maze 1. The error records, then, are not conclusive, although they do point to a saving resulting from increased instructions.

In learning time the groups are quite definitely ranked according

TABLE 3

COMPARATIVE GROUP RECORDS: MAZE 2 (CONTROL)

Group	Av. trials to learn	Av. total errors	Av. time to learn	Av. final time
1	11.7	54.5	4.03 min.	11.2 sec.
2	12.0	42.3	4.03	10.8
3	11.9	34.6	3.83	11.0
4	11.7	37.8	3.98	10.7

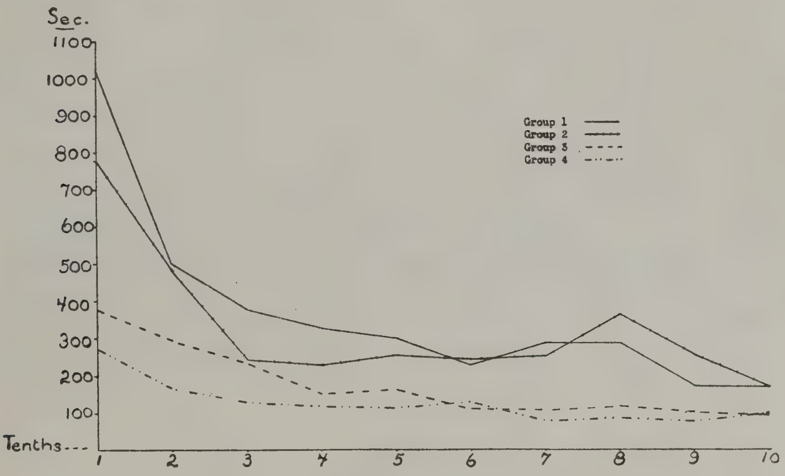
to amount of instructions in Maze 1. Group 4 required only about a third as much time as Group 1. This group received an additional visual demonstration. In the control maze the difference is very slight, less than 5% between the slowest and the fastest. This certainly points to a saving of time due to augmented instructions.

In final time there is no marked variation attributable to instructions. The groups rank in much the same order in both mazes, so there is no reason to believe that final time is a function of the mode of instruction. Liggett (28) found that time and errors are unrelated factors in animal maze learning. Average final time is apparently another unrelated factor, at least under our present conditions.

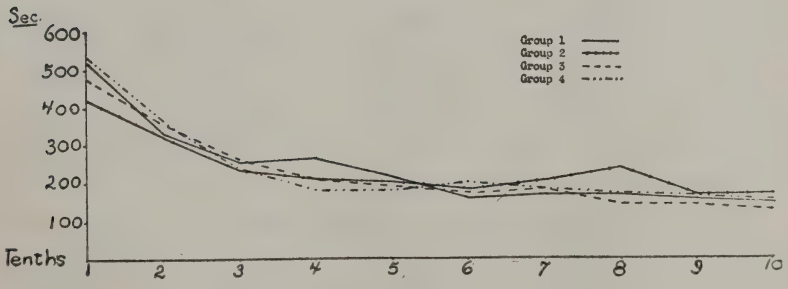
Wang (43) found that (*a*) with one exception, verbal guidance operated to decrease the number of trials required to learn the maze, the total number of errors, and the average number of errors per trial; (*b*) the efficacy of the guidance as measured by the trial-and-error records varied with the amount of guidance given. In a general way, its effectiveness first increased and then decreased, as the number of guided trials was increased. Smith (37) explains the more efficient learning on the part of the better-instructed groups as due to insight. He found that, when conditions permit, human subjects tend to react to a maze as a total situation and therefore with insight. Hunter attributes such differences to symbolic processes. He says, "Some problems, like the maze situation, do not lend themselves to solution in symbolic terms. While learning the ordinary maze that is traced with a pencil, the human subject manifests many verbal responses, but these enable him to learn no more quickly than the subject who depends upon random manual responses alone. If, however, the order of the turns can be designated verbally . . . . . . then symbolic processes may be used with profit in the solution of the problem" (15, pp. 330-331).

Vincent curves for errors are shown in Figure 2. In Maze 1 there is a tendency for the curves of Groups 1 and 2 to follow much the same path, as do those of Groups 3 and 4. The latter two groups start at a level of much greater efficiency, with a gradually sloping, even curve, whereas the two groups receiving the least instruction have a sharp initial drop, with many more peaks and plateaus. In the second maze, however, the curves for all four groups run close together. Vincent curves for number of trials and time are not shown here, but have a very similar form.

There does not seem to be a consistent trend to the comparative variability of the groups in Maze 1. The coefficient of variability, (V), for all four quantitative factors, is shown in Table 4. This is computed according to Pearson's formula $V = \frac{100\,\sigma}{\text{Average}}$. This measure is used because the *S.D.*, although the most reliable measure of variability in a distribution that approaches the "normal," is not very reliable when the distribution is considerably skewed, or when



Maze No. 1



Maze No. 2

FIGURE 2
Vincent Curves of Learning Time

groups are compared whose means are not the same or nearly the same, as is the case here. Group 4 is the most variable in trials, learning time, and final time, but Groups 1 and 2 are most variable in errors. Group 2 is least variable in errors, and Group 1 in final time. Thus, there is a slight tendency toward increasing variability with increased instructions, for number of trials, time, and final time, and a decreasing variability for number of errors.

Although the *S.D.* would be an adequate measure of the variability in Maze 2, *V* is used instead, in order that it may be comparable with Maze 1. The coefficients are shown in Table 5. Group 2 is in all cases the least variable, and Group 3 is most variable in all but final time. In comparing the groups in the two mazes, it will be seen that in a majority of cases the greater variability is in Maze 1. Group 3 is, however, an outstanding exception, being more variable in trials, errors, and learning time than in Maze 2. If increased instructions increase variability, then the results should have been just the opposite. Final time is in all four groups less variable in Maze 2. Wang (43) found that verbal instruction increased the variability in the records for errors and final time, but had no consistent effect upon the number of trials. Our results do not verify Wang's with respect to errors, yet it must be remembered that his problem was somewhat different. What variability occurs is perhaps due to variability in method of attack, verifying the work of Husband (20).

TABLE 4

COMPARATIVE VARIABILITY: MAZE 1

Values of *V*

Group	Trials	Errors	Learning time	Final time
1	159.82	271.63	114.79	56.25
2	113.37	189.19	91.61	61.37
3	145.73	105.60	160.13	57.24
4	187.31	121.04	182.31	90.10

TABLE 5

COMPARATIVE VARIABILITY: MAZE 2

Group	Trials	Errors	Learning time	Final time
1	150.86	127.34	120.40	46.41
2	105.42	127.19	94.95	45.50
3	160.92	195.38	185.16	56.85
4	151.71	177.25	155.78	60.89

TABLE 6
CORRELATIONS: INTELLIGENCE VS. PERFORMANCE, MAZE 1

Group	Trials	Errors	Learning time	Final time
1	.18±.22	.28±.21	.34±.20	—.70±.11
2	.33±.20	.06±.22	.13±.22	.27±.21
3	.02±.22	—.13±.22	—.07±.22	.27±.21
4	.82±.07	.81±.07	.53±.16	—.55±.15

In computing correlation coefficients between intelligence test rank and rank in the various quantitative aspects of the learning process, Spearman's rank difference formula ($\rho = 1 - \frac{6 \Sigma D^2}{N(N^2-1)}$) was used. The probable error was computed from the formula $P.E._r = \frac{.7063\ (1-r^2)}{\sqrt{N}}$, r being found from our value of ρ by the table on page 192 of Garrett's *Statistics in Psychology and Education.* Correlations for Maze 1 are found in Table 6.

With the first three groups, the correlations are low, and the *P.E.* is quite high. But Group 4 shows a significantly high positive correlation with trials, errors, and learning time, and a high negative correlation in the case of final speed. In all four cases the coefficient is at least four times as great as the *P.E.* The only high coefficient among the other groups is a negative correlation with final time, which Group 1 shows. It would seem that the more complete the instructions (verbal plus visual), the greater the effect of intelligence on the performance. Smith (37) says that the maze problem as ordinarily set is such as to preclude any use of insight. It may be that the difference between the performance of Group 4, the most completely instructed group, and that of the other groups is the difference between learning with and without insight, if we mean by insight a relatively fixed set. The tendency to a negative relationship between intelligence and final speed is in line with the results of Wang (43) and Waters (45). This may be due to the length of time required to translate symbols into explicit behavior, or to the increased automatization of behavior, which reaches its climax in the final trials, when all errors have been eliminated.

In Maze 2, when all groups are ranked together, negative correlations of .13 for trials, .02 for errors, and .06 for learning time are obtained; and a positive correlation of .11 for final time (see Table

7). These figures do not compare at all favorably with those of previous investigators. Warden (44) found a correlation of .37±.09 between number of trials and Army Alpa test scores, and a correlation of .30±.097 between trials and Thorndike test scores. Koch (25) found a correlation of .88±.04 between maze learning and the Miller Mental Ability Test.

TABLE 7

CORRELATIONS: INTELLIGENCE VS. PERFORMANCE, MAZE 2

All groups combined	Trials	Errors	Learning time	Final time
	—.13±.11	—.02±.11	—.06±.11	.11±.11

Hunter (14) obtained coefficients of .17±.094 for trials, .34±.087 for errors, and .45±.08 for total time, in correlating the data of a complex maze with Otis scores. With a simple maze, more comparable to ours, his correlations with Otis scores run much lower: .03±.101 for trials, and .23±.101 for total time. Warden and Koch both used more complex mazes than ours, and it seems possible that the degree of correlation may have some relationship to the complexity of the maze. According to Hunter (14), "the simpler the maze, theoretically, the less opportunity there is for chance to affect the records and the greater is the amount of control possible over the subject." And again, "So far as disturbance by chance factors during learning is concerned, the simpler the maze the more dependable its data." Spence and Townsend conclude that "correlations indicate a fairly high positive correlation between general intelligence and motor learning as measured by learning a maze" (high relief finger maze). . . "The maze is highly reliable in determining group differences, but it is not so for making distinctions in individual ability" (38, p. 128).

The methods of attack used by the subjects were classified as motor, visual, and verbal. It was necessary to rely upon introspective reports to obtain any data as to this factor, and, as the subjects were not trained in introspection, these data may not be as reliable as those obtained by more objective methods.

Warden's (44) criteria were used for classification. Under the verbal, or word reaction, group were included "attempts to memorize the direction and order of turns by attaching verbal symbols to them. The most characteristic response under this method was to verbalize the number of turns in one direction, then the number in the opposite direction, and so on through the series. The visual imagery method involved a reported attempt on the part of the subject to determine the direction of the turn at each point by referring to a more or less complete visual image of the maze pattern. Under the motor method the selection of direction was understood to be largely in terms of the kinaesthetic modality; a muscular control being used rather than either a verbal or imaginal one" (p. 248). As in Warden's experiment, the classification was based on the method *primarily* used, i.e., the one that finally brought success. Of course, probably no subject used only one of these methods, even at one time, but all were able to distinguish a method which seemed to stand out as being more predominant than the others, and which seemed to be principally responsible for the learning of the maze.

Distinct differences in the groups were indicated by the data obtained (Table 8). In the first place, the more complete instructions the group was given, the more the subjects tended to use a verbal method of attack. The motor and visual methods decrease correspondingly. In all four groups, without a single exception, the best record for trials, errors, and learning time was made by those using the verbal method, and the poorest by those using the motor control, with the visualizers ranging somewhere in between the two.

In the control maze (Table 9) the distribution of methods of

TABLE 8

Comparison of Performances with Different Methods of Attack, Maze 1

Group	Method of attack	No. of subjects	Av. trials to learn	Av. total errors	Av. time to learn	Av. intell. decile
1	Motor	4	15.8	71.0	7:45	6.3
	Visual	5	8.8	40.2	5:43	3.8
	Verbal	1	5.0	15.0	1:53	4.0
2	Motor	3	19.7	110.0	9:40	5.0
	Visual	5	6.4	37.2	4:11	3.6
	Verbal	2	5.0	10.5	2:27	7.5
3	Motor	1	17.0	60.0	6:18	6.0
	visual	4	7.5	33.8	3:39	4.3
	Verbal	5	7.0	9.4	1:44	5.0
4	Motor	1	19.0	49.0	5:24	8.0
	Visual	2	17.5	48.5	3:37	8.0
	Verbal	7	1.9	10.9	1:16	3.4

attack is very similar to that found by Warden. His subjects were classified as 29% motor, 30% visual, and 41% verbal, under instructions similar to ours in Maze 2. Our distribution is 30% motor, 35% visual, and 35% verbal. In this maze we find the same consistent superiority of the verbal type as in Maze 1, and inferiority of the motor type. It is notable that the greatest difference in Maze 1 is in Group 4, in which the verbalizers required only one-tenth as many trials as the motor type, and the least difference is in Group 1, where the corresponding fraction is less than one-third. Since Group 4 received a visual demonstration, it appears that verbalization is most effective when it is of a specific sensory (visual) nature.

Warden found that the average score of the word-reaction group

TABLE 9

COMPARISON OF PERFORMANCES WITH DIFFERENT METHODS OF ATTACK, MAZE 2

All groups combined.

Method of attack	No. of subjects	Av. trials to learn	Av. total errors	Av. time to learn	Av. intell. decile
Motor	12	25.7	80.8	7:35	5.3
Visual	14	7.8	31.8	2:58	4.2
Verbal	14	5.7	19.1	1:58	5.1

TABLE 10

AVERAGE INTELLIGENCE RANKING OF THOSE USING EACH METHOD OF ATTACK, MAZE 1

Group	Method of attack	No. of subjects	Av. intell. decile
1	Motor	4	6.3
	Visual	5	3.8
	Verbal	1	4.0
2	Motor	3	5.0
	Visual	5	3.6
	Verbal	2	7.5
3	Motor	1	6.0
	Visual	4	4.3
	Verbal	5	5.0
4	Motor	1	8.0
	Visual	2	8.0
	Verbal	7	3.4

on the Alpha and Thorndike tests was over 11% higher than for the motor group. We find a similar relationship in all but Group 2 in Maze 1, and in Maze 2 when the records of all groups are combined. (Table 10). However, our visual group is in general the highest of the three.

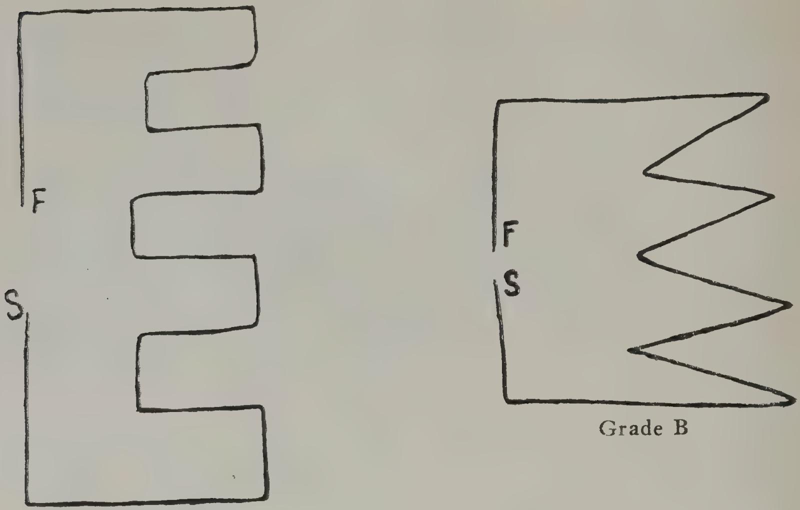
Warden had his subjects reproduce graphically, without vision, the true path of the maze, and found that the word-reaction group was "characterized by general proportion and neatness and by angularity of turns, the motor types on the other hand by a disproportionate sprawling general pattern, and absence of angular turns." Although our technique in reproducing the path was a little different from Warden's, we find far better reproduction from the verbal group than from the motor group (Table 11).

For convenience of treatment we have classified the reproductions into four groups (see Figure 3). Grade A consists of those in which the direction and order of every move was given correctly. Grade B includes those which were perfect except for the *number* of alternations. In every case the number was fewer than it should have been. Grade C contains those which bore a fair resemblance to the true

TABLE 11

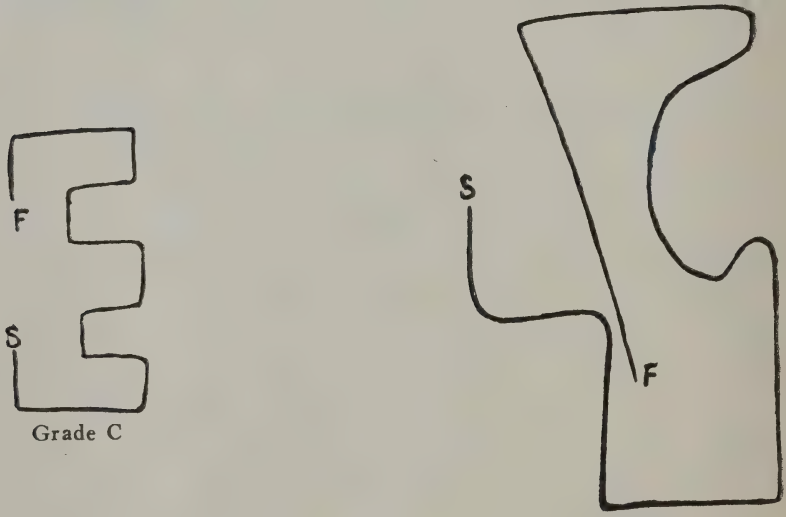
RELATIONSHIP OF GRADE OF REPRODUCTION TO MODE OF ATTACK

	Grade			
Mode of attack	A	B	C	D
	Group 1			
Motor	0	0	1	3
Visual	0	1	4	0
Verbal	0	1	0	0
	Group 2			
Motor	0	0	2	1
Visual	1	3	0	1
Verbal	0	0	2	0
	Group 3			
Motor	0	0	0	1
Visual	2	1	0	1
Verbal	2	1	2	0
	Group 4			
Motor	0	0	0	1
Visual	1	1	0	0
Verbal	4	1	2	0
	Total			
Motor	0	0	3	6
Visual	4	6	4	2
Verbal	6	3	6	0



Grade A

Grade B



Grade C

Grade D

FIGURE 3
Sample Reproductions of True Path
S—start, *F*—finish

TABLE 12

Distribution of Grades of Reproduction of True Path Among the Groups

Grade	Group 1	2	3	4
A	0	1	4	5
B	2	3	2	2
C	5	4	2	2
D	3	2	2	1

path, but which had various types of mistakes, such as too small or too great angles, wrong order of turns, etc. The very poor ones are classed as Grade D. These showed practically no idea of the system of the maze, had the wrong order to turns, and the angles were generally incorrect.

The distribution of the grades among the groups is shown in Table 12. It is quite evident that the grade of reproduction increases with the amount of instruction given. In general, those who made the best reproductions were those whose performances in the maze were also of a high order.

The relationship of mode of attack to grade of reproduction is shown in Table 13. The visual and verbal attacks yielded by far the best reproductions, the verbalizers having a little the better records. Warden found no special type of reproduction characteristic

TABLE 13

Comparison of Mode of Attack Used in the Two Mazes

Group	Both motor	Both visual	Both verbal	Motor to vis.	Vis. to verbal
1	1	3	0	1	1
2	2	2	1	0	1
3	1	2	3	0	1
4	1	0	4	0	0
	5	7	8	1	3
	Verb. to mot.	Mot. to verb	Vis. to mot.	Verb. to vis.	
1	1	2	1	0	
2	0	1	2	1	
3	0	0	1	2	
4	0	0	2	3	
	1	3	6	6	

of the visual method, but their drawings contained characteristics of both of the other methods. According to our system of grading they would have ranked between the other two methods. Thus our work may be considered to verify Warden's results.

Table 13 indicates that the same method of attack was not necessarily used in both mazes. The introspective reports show this clearly. A typical statement was, "I started out trying to visualize in the second maze the way I did in the first; but I got so confused that I gave it up and just let my hand sort of find its own way around" (Subject 4H6). Just half the subjects used the same method of attack in both mazes. In Group 1 the instructions were amplified in the second maze, and, of those who change their method, four changed to a more efficient method (motor to visual or verbal, visual to verbal), while only two changed to a less efficient method (verbal to motor or visual, and visual to motor). Group 2 had the same instructions in both mazes, and two changed to a more efficient method, while three changed to a less efficient one. Both Group 3 and Group 4 had less complete instructions in the second maze. Only one subject in Group 3 and none in Group 4 changed to a more efficient method, while three in Group 3 and five in Group 4 changed to a less efficient method. Thus there is a strong tendency for the amount of instructions to be correlated with the efficiency of the method employed.

Summary of Results

1. Increasing instructions tended to increase the efficiency of the learning process, as evidenced by the number of trials and length of the learning period. In total trials, time, and errors, the two most completely instructed groups are much superior to the two least instructed groups. No positive relationship was found between amount of instructions and final time.
2. The results obtained from the control maze show the groups to be well equated.
3. The learning curves of the best instructed groups indicate an initial superiority over the less-instructed groups, followed by a diminishing difference. Between Groups 1 and 2, and between Groups 3 and 4, there is little difference in the curves.
4. The most fully instructed group was the only one to show a significant correlation between intelligence deciles and performance in the experimental maze. Significant positive coefficients were found

to hold with trials, errors, and learning time, and a significant negative coefficient with final time. No significant correlations were found between intelligence deciles and performance in the control maze. This may be due to the simplicity of the maze, as there is some evidence for a tendency for the correlation to increase with increased complexity of the path.

5. The increasing instructions increased the tendency to use a verbal method of attack, rather than a visual or motor method.

6. There was a tendency for those of highest intelligence deciles to use the visual attack, followed closely by the verbalizers, while those of lowest intelligence tended to use a motor attack.

7. The better the performance of the subject in the experimental maze, the better was his reproduction of the true path.

8. The more complete the instructions, the more accurate the reproduction of the true path tended to be.

9. There was a tendency for those who used a verbal attack to make a superior reproduction of the true path, although the visual group did nearly as well.

10. Half the subjects used the same method of attack in both mazes. The majority of the other half changed to a superior method of attack if their instructions were increased (Group 1), and changed to a less efficient method of attack if their instructions were decreased (Groups 3 and 4). If the instructions remained the same (Group 2) the tendencies in each direction were practically equal.

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PREMIÈRE PARTIE: L'EFFET DES INSTRUCTIONS VERBALES SUR L'APPRENTISSAGE DU LABYRINTHE À STYLET

(Résumé)

Quatre groupes, chacun de dix sujets (groupés selon les résultats des tests d'intelligence) ont appris à tracer un labyrinthe à stylet (Labyrinthe II) avec les instructions usuelles. On a employé les résultats de cette expérience pour faire des comparaisons (le contrôle). Ensuite ils ont appris un labyrinthe pareil (Labyrinthe I). Chacun des quatre groupes a reçu des instructions verbales différentes [(*a*) minima, (*b*) moyennes, (*c*) maxima, et (*d*) des instructions verbales maxima plus une exposition visuelle]. On a comparé les résultats ainsi obtenus avec la série de contrôle. On a trouvé que l'efficacité de l'apprentissage varie directement la quantité de l'instruction verbale, en durée totale, en essais et erreurs, mais tend à une relation inverse en durée finale. Le groupe le plus instruit a été le seul qui a montré une corrélation signifiante entre les déciles d'intelligence et le rendement dans le labyrinthe expérimental. Plus d'instructions ont augmenté la tendance à se servir d'une méthode verbale d'attaque plutôt qu'une méthode visuelle ou motrice. Les sujets aux déciles les plus élévés d'intelligence ont tendu à se servir de l'attaque visuelle, suivis de près par les sujets se servant de l'attaque verbale, tandis que ceux aux déciles d'intelligence les moins élevés ont tendu à se servir d'une attaque motrice. Ceux qui ont eu le meilleur rendement dans le labyrinthe d'entraînement ont le mieux reproduit du sentier véritable (cette reproduction a été un dessin du sentier véritable fait avant que le sujet n'ait vu le labyrinthe). Et plus les instructions ont été complètes, plus la reproduction du sentier véritable a tendu à être exacte.

LAMBERT ET EWERT

I. TEIL: DIE EINWIRKUNG VON WÖRTLICHEN ANWEISUNGEN AUF DAS ERLERNEN EINES GRIFFELLABYRINTHES

(Referat)

Es wurden vier Gruppen, bestehend aus je zehn Versuchspersonen, den Zahlen gemäss, die an Intelligenzprüfungen erreicht worden waren, einander gleichgestellt (equated according to intelligence scores). Alle Gruppen lernten dann ein Griffellabyrinth (stylus maze) (das Labyrinth II) mit Hilfe festgesetzter Anweisungen auszuspüren (trace). Die Befunde dienten zum Vergleich (zur Kontrolle). Dann wurde ein ähnliches Labyrinth (das Labyrinth I) bemeistert. Die wörtlichen Anweisungen waren bei jeder der vier Gruppen anders: (*a*) minimale, (*b*) normale, (*c*) maximale, und (*d*) maximale wörtliche Anweisungen mit Hinzufügung einer visuellen Darstellung. Die so erhaltenen Befunde wurden dann mit der Kontrollserie verglichen. Es zeigte sich, dass die Tüchtigkeit der Bemeisterung (efficiency of learning), mit Bezug auf den gesammten Zeitverbrauch und die Zahl der Versuche und Fehler, direkt mit der Quantität der wörtlichen Anweisungen variirte, dass sie aber etwas in der Richtung eines negativen Verhältnisses zu dem Zeitverbrauch in dem letzten Versuche neigte. Die Gruppe, die die meisten Anweisungen erhalten hatte war die einzige, bei der sich eine bedeutsame Korrelation zwischen Intelligenzrang (eine bis zehn) (intelligence deciles) und Leistung an dem Versuchslabyrinth zeigte. Vermehrte man die Anweisungen, so verstärkte sich die Neigung, eher eine

verbale als eine visuelle oder eine motorische Angriffsmethode zu gebrauchen. Es zeigte sich bei Vertretern der höchsten Intelligenzkategorien eine Tendenz zum Gebrauch der visuellen Angriffsmethode. Ihnen folgten nahe die "verbalisten" (verbalizers) während die Vertreter der niedrigsten Intelligenzkategorien eher eine motorische Angriffsmethode gebrauchten. Je besser die Leistung an dem Übungslabyrinth (training maze), desto besser war die Nachbildung (eine Skizzierung des richtigen Pfades, die ausgeführt wurde ehe die Vp. das Labyrinth gesehen hatte). Und je vollkommener die Anweisungen, desto genauer war im Allgemeinen die Nachbildung (reproduction) des richtigen Pfades.

Lambert und Ewert

PART II: THE EFFECT OF VERBAL INSTRUCTIONS UPON THE FORMATION OF A CONCEPT*[1]

From the Department of Psychology of the University of Vermont

P. H. Ewert and J. F. Lambert

This investigation was carried on simultaneously with that of "Part I, The Effect of Verbal Instructions upon Stylus Maze Learning." In the present study we are concerned with the "set" following minimal, standard, and maximal instructions upon the formation of a concept (ability to generalize). The terms, minimal, standard, and maximal instructions, are used in the same sense here as in our previous paper (4).

If language symbols are to be regarded as substitutes for manipulatory movements we should expect: (*a*) that the more complete the verbal instructions the less will be the manipulatory movements necessary to solve the problem; (*b*) that the more intelligent the subjects the more able they will be to deal with language symbols, and that they will rely more upon language symbols as the problem becomes more complex; (*c*) that the more complete the instructions the higher will be the correlation between performance and intelligence, and (*d*) that between activities in which language symbols play an important rôle there will be high correlations. These expectations were actually verified in this study.

In a former study Ewert (1) showed that spatial localization is greatly influenced by verbal instructions. When various receptors are stimulated simultaneously, the verbal instruction or the "set" determines which receptor will be dominant in motivating the behavior. The dominance of a receptor in a given environmental situation depends upon the nature of the "set." Thus the human being is capable of developing a consistent response to either a visual, tactile, kinaesthetic, auditory, or any other sensory stimulus (depending in each case upon the verbal instructions), while inhibiting the sense data from those receptors which may serve as distractors. It was,

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[1] This research was conducted at the University of Vermont, from October 15, 1929, to June 1, 1930.

however, found that there are unconditioned (primitive) forms of behavior which are not so readily influenced by verbal instructions. Thus the illusory visual disorientation during inverted vision did not change in a 14-day period of continuous inversion during waking hours, i.e., the topsy-turvey visual illusion resulting from inverting lenses was not affected by practice (the subject's attempt to reharmonize the illusory visual experience, conflicting eye-head and eye-body movements, etc., with normal auditory, tactile, kinaesthetic, and other established habits). In fact, it was found that in some instances the unconditioned illusion was so strong that it could not be verbally (voluntarily) inhibited. An example of this was obtained in the illusion of inverted movement. While riding in a street car, in an automobile, or in an elevator, the subject experienced a very strong illusion of inverted movement. When the vehicle was actually going west there was a strong illusion of going east, and vice versa. Going up in an elevator gave the illusion of going down, and vice versa. Once started, the illusion of inverted movement persisted even with eyes closed. The subjects tried in vain to inhibit it verbally. This makes it appear that verbal instructions have discriminatory effects upon various types of behavior. It has been found (5, 7, 8), and our studies verify these findings, that verbal instructions increase the variability of response. This further suggests that verbal instructions affect subjects variously, and the same subject variously at different times. It thus becomes evident that we are dealing with highly complex phenomena.

However, in spite of this complexity, it is possible to deduce some of the underlying factors governing the effect of verbal instructions upon specific types of behavior. This is especially true if the proper controls are introduced, if the instructions are clear and precise, and if care is taken to present them alike to all subjects.

Outline of Experiment

The technique used in this investigation has never before appeared in published experimental form.[2] It is based on the problem described by Hunter (3, pp. 331-333). Its origin is attributed to Dr. J. C. Peterson. Three circles are drawn on a piece of paper in such a manner as to form a triangle, and numbered 1, 2, and 3. Three discs, graduated in size, are placed in the first circle, arranged in order of size, with the largest at the bottom. The problem is to transfer the discs from Circle 1 to Circle 2 in the least possible number of moves. Only one disc may be moved at a time, and it must be placed in one of the other circles, but not on another disc smaller than itself. When the method is learned for three discs, another disc is added, and so on. The elements of the problem remain the same, no matter how many discs are used, so that it is possible to make a generalization or to form a concept of the solution for any number of discs. However, as each disc is added, the problem becomes more and more complex and requires an increased number of moves which can also be stated in a simple mathematical formula.

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[2] Since this article has been in proof the author has seen reference to the investigation of Peterson and Lanier (5*a*) in which a method similar to the one here described was used.

It will readily be seen that this furnishes an excellent method for studying activity of the inductive inferential sort. Of course, it need not be maintained that all the subject's implicit behavior is translated into outward action, yet to a large extent this is true, as the subject must needs continually check his hypothesis (possible solutions) against fact (correct solution), and the hypotheses chosen are at least partially revealed by his manipulation of the discs.

It is possible that the subject will, through pure chance, manipulate the discs correctly, without the use of symbolic control. But, as the discs are added and the problem becomes more complex, this possibility becomes more and more remote, as the reader may easily discover for himself.

Data are here presented to shed light upon the following:

1. The effect of verbal instructions upon the number of trials, the number of manipulatory movements and the time of response.
2. Their effect upon the nature of the learning curve.
3. Their effect upon variability of performance.
4. Their effect upon the relation of performance to intelligence.
5. Correlations between stylus maze learning and ability to form concepts.

EXPERIMENT

Apparatus. The apparatus for this experiment consisted of a sheet of white paper, 28.0 cm. by 21.5 cm., on which were drawn three circles, 55 mm. in diameter, and numbered 1, 2, and 3, forming a triangular pattern; and eight cardboard discs, graduated in size from 18 mm. to 47 mm. in diameter, and numbered from 1 to 8, beginning with the largest.

Procedure. *S* was seated at the same table used in the stylus maze experiment, the box used to hold the maze being placed at one end, and serving again to conceal *E*'s data. *S* was handed the instruction sheet and *E* placed the paper containing the three circles on the table in front of *S*, affixing it thereto with thumbtacks. Discs 1, 2, and 3 were placed on Circle 1. *S* was allowed as much time as he wished to read the instructions but was not allowed to manipulate the discs. When he signified that he understood the instructions, he was asked to repeat them. If he missed any essential points, he was told to reread the instruction sheet. When he could repeat the contents satisfactorily, *E* proceeded with the experiment, saying, "Ready? Go."

The instructions given the different groups were as follows:

Group 1:

> "You are given three circles, 1, 2, and 3. On Circle 1 you will find a certain number of discs. The largest disc is at the bottom; the next largest is next to the bottom, etc., so that the smallest discs is on the top. You are to transfer these discs to Circle 2 in the least number of moves possible so that they will be in the same order. You may move only one disc at a time. You may move only discs which are on top of a pile or which are alone. You must not place a larger disc upon a smaller disc. A disc moved from one circle must be placed in one of the other two circles."

Group 2: Same as for Group 1 plus the following:

> "Try to find a general rule by which this problem may be solved, and which will be applicable to any number of discs whatsoever. Try also to find a general rule which will enable you to compute the least number of moves possible for any number of discs whatsoever."

Group 3: Same as for Group 1 plus the following:

> "You will be most successful if you move the discs according to the following system: if the number of discs is odd, move first to the circle to which you want to go eventually; if the number of discs is even, move first to the circle to which you do not want to go eventually. Then continue by moving the discs with the odd numbers in a clockwise direction, and the discs with the even numbers in a counter-clockwise direction. Count your moves as you go along."

Group 4: This group was given the same instructions as Group 3, but in addition *E* gave a demonstration of the correct method by moving the discs, using three discs for an example.

While *S* was engaged in transferring the discs, *E* watched from the opposite side of the table, timing the performance from the word "Go" until the last disc was placed on Circle 2, and counting the number of moves. When *S* had completed one trial, the discs were placed back on Circle 1. If *S* had not used the correct method, *E* said, "Try to do it in fewer moves." Otherwise nothing was said except the instructions for the next trial, "Ready? Go." This was repeated until *S* had made two perfect trials in succession. Then another disc was added to the pile, and *E* informed *S* that the instructions remained the same as before.

Three, four, five, six, seven, and eight discs were transferred successively in the manner described above. A rest period of 3 minutes was given after approximately each 10 minutes of actual manipulation. Rest was given only between trials. Conversation was carried on, but references to the problem itself were strictly avoided.

Spontaneous remarks made by *S* during the learning process were noted, but all questioning and introspection was left until the end, to prevent the giving of unintentional cues.

When *S* had finished the problem, i.e., had completed two successive perfect trials with 8 discs, he was asked for (*a*) a general statement of the most efficient method for transferring any number of discs, and (*b*) a formula for computing the least number of moves necessary for transferring any number of discs. For the latter question he was at first not allowed access to the data, and, upon his failure to give a satisfactory answer, was given *E*'s record sheet to peruse.

S was encouraged to tell all he could concerning his method of learning the problem, but no detailed introspection was requested or obtained.

Results. It was obvious from the start that this experiment was very difficult for these subjects. For several of them the time of actual manipulation approached a total of three hours, and one subject made nearly 15,000 moves. Reports of fatigue, both mental and physical, were the rule. However, in a study of this type it is a decided advantage to choose a problem which may be carried to varying degrees of difficulty, thus providing an adequate measure for extreme cases. Too often problems are so formulated that accurate measurements are limited to average performance; the inferior subjects are unable to do the problem and for the superior subjects it is too easy.

Learning period. Table 1 shows the average totals of trials, ex-

TABLE 1
COMPARATIVE PERFORMANCE

Group	Av. total trials	Av. excess moves	Av. total times
1	44.2	1154.6	8502.4
2	42.4	757.9	6220.2
3	15.1	300.8	2435.1
4	16.3	304.6	2481.8

cess moves, and learning time for the different groups. The figures for excess moves were found by subtracting from the total number of moves with each number of discs the number of moves which would have been necessary for the number of trials which he made, if he had made no mistakes. This is a much more representative value than the total moves, as the latter takes no consideration of the fact that a certain minimum number of moves is necessary, increasing with the number of discs.

Group 2 required slightly fewer trials than Group 1, and used only about three-fourths as many moves or as much time. Group 3 is far superior to both of them in all three measures. Group 4 is just slightly poorer than Group 3 in all criteria, but is much superior to Groups 1 and 2. The fact that Group 2 was instructed to try to find a system seems to have helped that group appreciably. The groups which were given a system by which to manipulate the discs did much better than the other groups, as might be expected; but even they found the problem very difficult. Groups 3 and 4 were given the same instructions with the exception of the demonstration which was given Group 4. As the latter group made a slightly poorer record than the former, it appears that the demonstration exerted a slightly detrimental effect on Group 4. It is more likely, however, that this difference is due to chance or to the variability of performance. In general, these data indicate that the more complete the verbal instructions the less are the manipulatory movements necessary to solve the problem. Demonstration apparently has a slight inhibiting effect upon this type of behavior.

Learning curves. Vincent type learning curves of excess moves are shown in Figure 1. The curves for Group 1 have an increasing tendency to start much higher and descend more rapidly than those of the other groups. Group 2 also starts rather high, and has a steep descent, but is almost without exception above Groups 3 and 4.

The curves of Groups 3 and 4 run very close t oeach other at most times. In the 3-disc section, however, Group 4 made no errors at all, indicating the efficiency of the demonstration; but in the 4- and 5-disc sections, this group made more errors than Group 3. This would seem to show that the demonstration had a beneficial effect on the manipulation of the number of discs with which the demonstration was effected, but that it had a detrimental effect on the manipulation of an increased number of discs. In general, the curves for Groups 3 and 4 are gradually sloping, and become increasingly so with increases in the number of discs.

Variability. The relative variability of the groups is shown in Table 2. The coefficients ($\frac{100\sigma}{\text{Average}}$) for trials, excess moves and learning time are very consistent for each group, and show a rather

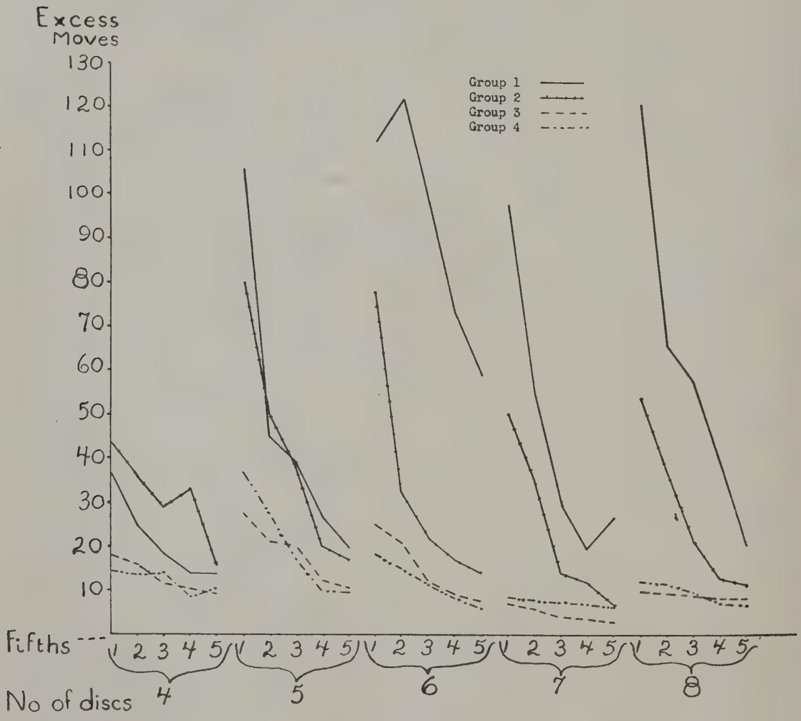

FIGURE 1
VINCENT CURVES OF EXCESS MOVES
(Average per individual)

TABLE 2

VARIABILITY COEFFICIENTS

Group	Trials	Excess moves	Total times
1	56.79	58.89	54.88
2	65.09	61.99	59.85
3	125.17	113.03	114.98
4	126.38	128.04	135.39

clean-cut difference between groups. Group 1 has a fairly low coefficient, with Group 2 somewhat more variable. Group 3 is about twice as variable as Group 2, and Group 4 is somewhat more variable than Group 3. The variability, then, increases as the instructions are increased. This may be interpreted to mean that as the instructions are increased, certain individuals are able to take advantage of the instructions to reduce the length of the learning period, while at the other extreme are individuals to whom increased instructions make comparatively little difference. It might be expected that the more intelligent the individual, the better would be his chance of being able to take advantage of the increased instructions. That phase will now be discussed.

Relation of performance to intelligence. Correlation of trials, moves, and time with intelligence test ranks are shown in Table 3. The coefficients are consistently high, and the *P.E.* is low. There seems to be no doubt but that the factors that make for high intelligence test scores are also very influential in the learning of this problem.

In Table 4 the coefficients are given for the learning of the manipulation of each number of discs. In general, the value of the coefficient is low at the start, increasing rapidly to the 5- or 6-disc section, followed by various fluctuations, with some increase in most cases. This may be interpreted as indicating a relatively greater

TABLE 3

CORRELATION COEFFICIENTS: PERFORMANCE *vs.* INTELLIGENCE

Group	Total trials vs. intell.	Total moves vs. intell.	Total time vs. intell.
1	.86±.054	.90±.038	.89±.042
2	.87±.050	.90±.038	.94±.022
3	.86±.054	.96±.018	.93±.026
4	.87±.050	.93±.026	.93±.026

TABLE 4

Correlation Coefficient: Intelligence *vs.* Performance with Each Number of Discs

Group	No. of discs 3	4	5	6	7	8
			A. Intelligence vs. number of trials			
1	.39±.19	.61±.14	.52±.16	.82±.07	.91±.04	.95±.02
2	.74±.10	.60±.14	.91±.04	.81±.07	.84±.06	.88±.05
3	.40±.18	.62±.13	.52±.16	.84±.06	.81±.07	.92±.03
4		.63±.13	.85±.06	.89±.04	.85±.06	.89±.04
			B. Intelligence vs. number of moves			
1	.32±20	.52±.16	.43±.18	.76±.09	.91±.04	.91±.04
2	.69±.11	.61±.14	.92±.03	.83±.07	.84±.06	.90±.04
3	.44±.81	.56±.15	.58±.14	.80±.08	.87±.05	.88±.05
4		.62±.13	.79±.08	.87±.05	.87±.05	.94±.02
			C. Intelligence vs. learning time			
1	.08±.22	.52±.16	.48±.17	.79±.08	.79±.08	.93±.03
2	.69±.11	.51±.16	.84±.06	.76±.09	.69±.11	.66±.12
3	.39±.19	.44±.18	.54±.15	.80±.08	.87±.05	.88±.05
4		.39±.19	.69±.11	.87±.05	.87±.05	.94±.02

predominance of "trial-and-error" learning at the start, with intelligence operating as a "weeding-out" process as learning progresses.

In connection with maze learning we have already pointed out that the relationship of intelligence seemed to increase with increased complexity of the problem. The same proposition holds true in this experiment. It would seem that the more the activity requires the use of symbolic thought processes, the greater the effect of intelligence on the performance.

Unfortunately, most of the investigators of problems of this type have not correlated their results with intelligence test scores. Haught (2), however, found correlations of .18 to .44 between IQ and various rational learning tests. Sullivan (6) also found that intelligence was an important factor in determining chance and speed of generalization.

Generalizations. That the problem was really not fully exhausted by these subjects is shown plainly by the generalizations which they were able to give. Two generalizations were requested from each subject—the method of transferring any number of discs in the least possible number of moves, and the number of moves necessary for any number of discs. The former were classified for convenience in treatment as follows: Grade A, statements covering

TABLE 5

GENERALIZATIONS OF METHOD

	Number of each grade			
Group	A	B	C	D
1	0	2	4	4
2	0	2	6	2
3	8	1	1	0
4	7	1	2	0

every move with any number of discs; Grade B, partial or incomplete statements applicable to any number of discs; Grade C, first move, any number of discs; Grade D, statements applicable to only one number of discs; those intended to be applicable to any number, but which would not work; or no statement at all.

From Table 5 it may be seen that no individual in Groups 1 and 2 was able to formulate a complete generalization for himself. In Groups 3 and 4 eight and seven individuals, respectively, were able to state the generalization which they had been given. In other words, no one of the forty subjects formulated a complete generalization. However, our criteria of performance, namely, trials, excess moves, and total time, give us data for the activity of the inferior as well as the superior subjects. Of the generalizations that were offered, those of Group 2 were slightly superior to those of Group 1; whereas Group 3 slightly exceeded Group 4. This shows that, in general, verbal instructions augmented ability to generalize.

The data for these correlations were obtained by averaging the rank of each subject in trials, errors, and learning time in the maze (4) and in trials, excess moves, and learning time in the concept problem. The averages thus computed may be considered as figures quite representative of the rank of the individuals in ability to learn the problems under the specific conditions present.

Correlations with maze. Although any correlation computed between performance in the maze (4) and in the concept problem should not be taken as being of more than suggestive importance, owing to the varied conditions and the size and distribution of the coefficients obtained, still they would seem to indicate a certain amount of relationship (Table 6). If there were any relationship, it would be expected that there would be a higher correlation between Maze 1 and the concept, where the groups have somewhat similar variations in the instructions, than between Maze 2 and the concept. Such is the case in all four groups. The only negative correlation is in Group 3. This might also be expected, since there is the greatest difference between the instructions Group 3 received in Maze 1 and those it received in the concept. However, Group 3, as the other groups, has more of a relationship to the concept (that is, a lower negative correlation) in Maze 1 than in Maze 2. Group 4, which shows a high correlation between performance in Maze 1 and in the concept, also had high correlations between performance in these two problems and intelligence test scores.

The foregoing data argue for the existence of an ability, which may be designated as "symbolic reasoning," (*a*) which is fairly well measured by tests, and (*b*) which is a vital factor in learning *when verbal instructions and visual guidance dominate the mental "set."* This is further substantiated by the superior records of those reporting a verbal mode of attack in maze learning (4).

TABLE 6

CORRELATIONS: MAZES *vs.* CONCEPT PROBLEM

Group	Maze 1 *vs.* concept	Maze 2 *vs.* concept
1	.30—.20	.14—.22
2	.39—.19	.08—.22
3	—.09—.22	—.22—.21
4	.82—.07	.24—.21

Summary. 1. Increased instructions were found to decrease the average number of trials and excess moves, and amount of learning time.

2. Learning curves of excess moves show a pronounced tendency for increased instructions to increase the initial efficiency and to cause a smoother and more gradual curve. The demonstration given Group 4, however, increased efficiency only for the particular number of discs used in the demonstration, and thereafter has a detrimental effect, which has a tendency to "wear off" as learning progresses.

3. Increased instructions are very definitely accompanied by increased variability.

4. High correlations were found between performance and intelligence deciles. In general, the correlations were lowest at the start, increasing rapidly for a time, then gradually toward the end of the learning process.

5. The individuals in the Groups (3 and 4) which were given a generalization in their instructions were in most cases able to repeat the generalizations at the end; but the individuals in those groups (1 and 2) not given a generalization were in no case able to formulate a complete one.

6. Higher correlations were found between performance in the instructed maze group and the instructed concept group than between the non-instructed maze group (control maze) and the non-instructed concept group. A significantly high correlation was found between Group 4's performance in Maze 1 and the concept problem.

7. The more intelligent the subjects the more they are able to deal with language symbols, and they rely more upon such symbols as the problem increases in complexity.

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DEUXIÈME PARTIE: L'EFFET DE L'INSTRUCTION VERBALE SUR LA FORMATION D'UN CONCEPT

(Résumé)

On a dessiné trois cercles sur un morceau de papier en sorte de former un triangle, numérotés 1, 2 et 3. Dans le premier cercle on a placé des disques, gradués en grandeur, rangés en ordre de grandeur, le plus grand au fond. Il s'agit de transférer les disques du cercle 1 au cercle 2 avec le plus petit nombre possible de mouvements. On ne peut faire mouvoir qu'un disque à la fois, et il faut le placer dans un des autres cercles, mais non sur un disque plus petit. On a demandé trois généralisations, à savoir, (*a*) la position du premier mouvement pour chaque disque additionnel, (*b*) la direction du mouvement pour les disques impairs et pairs, et (*c*) une formule qui décrit le plus petit nombre de mouvements nécessaire pour chaque disque ajouté. On a fait subir ce problème à quatre groupes de sujets, chacun avec des quantités variantes d'instruction verbale.

On a trouvé que plus d'instruction a diminué le nombre moyen d'essais et de mouvements non nécessaires, et la quantité de temps de l'apprentissage. Plus d'instruction a été très définiement accompagnée de plus de variabilité. On a trouvé des corrélations élevées entre le rendement et less déciles d'intelligence. En général, les corrélations n'ont pas été élevées d'abord, se sont élevées rapidement pendant quelque temps, puis peu à peu à la fin de l'apprentissage. On a trouvé des corrélations élevées significantes entre le groupe le mieux instruit dans cette étude et le groupe le mieux instruit dans l'étude du labyrinthe (Voir Première Partie, cette revue). Plus les sujets ont été intelligents, plus ils ont pu employer les symboles du langage et ils ont plus dépendu de tels symboles avec la plus grande complexité du problème. Cette étude indique l'existence d'une capacité qu'on peut appeler "le raisonnement symbolique," (*a*) qu'on peut mesurer au moyen des tests, et (*b*) qui est un facteur vital de l'apprentissage quand les instructions verbales et l'exposition visuelle dominent la situation.

EWERT ET LAMBERT

II. TEIL: DIE EINWIRKUNG WÖRTLICHER ANWEISUNGEN AUF DIE BILDUNG EINES BEGRIFFS

(Referat)

Es wurden auf einem Stück Papier drei Kreise so gezeichnet, dass sie einen Dreieck bildten, und respektiv mit den Zahlen 1, 2, und 3 nummeriert. In dem ersten Kreis wurden Disken angelegt, die rangmässig nach Grösse geordnet worden waren, wobei der grösste Diskus unten lag. Die Aufgabe war, die Disken von dem Kreis 1 in den Kreis 2 mit so wenigen Zügen wie möglich zu übertragen. Es durfte nur ein Diskus auf einmal versetzt werden; er musste auf einen der Kreise gelegt werden, aber nicht auf einen Kreis der kleiner war als er selber. Es wurden drei Verallgemeinerungen verlangt nämlich: (*a*) die Lage des ersten Zuges bei jedem hinzukommenden Diskus, (*b*) die Richtung der Bewegung bei unebenen und ebenen (odd and even) Disken, und (*c*) eine Formel zur Beschreibung der minimalen Zahl der zu jedem hinzugefügten Diskus nötigen Züge. Diese Aufgabe wurde vier Gruppen von Versuchspersonen vorgelegt. Die Summe der Anweisungen war bei jeder Gruppe eine andere.

Es zeigte sich, dass eine Vermehrung der Anweisungen die mittlere Zahl

der Versuche und der überflüssigen Züge und auch die Lernzeit verminderte. Eine Vermehrung der Anweisungen ging ganz bestimmt mit einer Zunahme an Variabilität einher. Es zeigten sich hohe Korrelationen zwischen der Leistung der Vp. und ihrem an einer Intelligenzprüfung bestimmten Rang. Im Allgemeinen waren die Korrelationen am Anfang nidrig; sie nahmen dann, eine zeitlang rasch und gegen dem Ende des Lernens langsam, zu. Es erwiesen sich bedeutsam hohe Korrelationen zwischen der am völligsten unterrichteten Gruppe in der Labyrinthuntersuchung (Siehe Teil I in dieser Zeitschrift). Je intelligenter die Versuchspersonen waren, desto leichter war es ihnen, mit linguistischen Symbolen umzugehen, und bei zunehmender Kompliziertheit der Aufgabe stützten sie sich immer mehr auf solche Symbole. Diese Untersuchung spricht dafür, dass es eine Fähigkeit gibt, die als "symbolische Schlussfolgerung" bezeichnet werden kann, die (*a*) mit Prüfungen gemessen werden kann und die (*b*) einen wesentlichen Bestandteil des Lernens ausmacht wenn wörtliche Anweisungen und visuelle Darstellung (exposure) die "Lage" (set) beherrschen.

EWERT UND LAMBERT

TWO IMPORTANT FACTORS IN THE SIZE AND SHAPE OF THE FORM FIELD AND SOME OF THEIR RELATIONS TO PRACTICAL PERIMETRY*

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C. E. Ferree and Gertrude Rand

Introduction

The factors which affect the size and shape of the form field may be divided into two classes: those which affect the results for a given eye and those which affect the results from eye to eye.

To the former class belong such factors as size of stimulus, relation of stimulus to background, intensity of illumination, breadth of pupil, steadiness of fixation, state of adaptation of the retina, preexposure and method of presenting the stimulus (stationary or moving stimulus); to the latter such factors as curvature of the cornea, errors of refraction in the central and peripheral field, acuity in the peripheral field, the sensitivity gradient from the center to the periphery of the field, shape of face, age, and sex.

Certain of the more important of these factors will be selected for study. We have already published data on errors of refraction in the central field, age, and sex for 200 cases (2). We have obtained, but not as yet published, results on breadth of pupil as a factor. Also we have developed a feasible and practical method of studying the refractive conditions in the peripheral field and have obtained curves for 21 eyes showing the conditions as far out as 60 degrees.

Two very important factors in the size and shape of the form field are size of stimulus and relation of stimulus to background. These factors are important not only because of the magnitude of their effects, but because of the ease and feasibility with which they may be manipulated in the development of method. It has been the purpose of the present experiments to study the effect of these factors both separately and in interaction. The chief incentive has been the extension of our knowledge of factors. There have been, how-

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ever, other incentives related to the applications of perimetry. A very few of these only will be noted here.

1. We have shown that great sensitivity can be added to scotometry with the form field stimulus by using stimuli of low visibility (1, 3). The visibility of the stimuli may be decreased by decreasing their size, their brightness difference from the background, the intensity of the illumination, and by a combination of any two or all of these means. However, in the selection of stimuli for the search for scotomas, we need to know the size of field for which the examination can be made with the various stimuli. The present study gives a fairly accurate idea of the size of field that may be expected with different sizes of stimulus for different relations of stimulus to background under 7 ft.-c. of illumination.

2. A corresponding increase of sensitivity may also be expected in the use of stimuli of low visibility in perimetry for the detection of the nasal step and other irregular cuts and indentations in the field. However, stimuli of low visibility are not suitable for use in cases where only the nerve fibers which reach the far periphery of the retina are affected. For this and other reasons to be given later in the paper, we again need to know what regions of the field can be examined with stimuli of various degrees of visibility.

3. Two reasons may be cited in explanation of the great sensitivity of colored stimuli for the detection of pathological disturbances: (*a*) their low visibility as compared with white on black or black on white for equal sizes and equal intensities of illumination, particularly for the paracentral and peripheral portions of the field; and (*b*) the possibility of a greater effect of pathological conditions on the color than on the form sense. A great deal of help can be had in the evaluation of these two possibilities of explanation by the use of form and color stimuli of equal visibility for the zones or regions of the field under examination. Form and color stimuli which give coincident limits have approximately equal visibility for the part of the retina in question. Data obtained in this study give the limits for form stimuli of varying degrees of visibility. These data will be of service in the selection of form stimuli for a comparison with color stimuli.

4. We have learned that in using our perimeter some examiners, overlooking the effect of relation to background on the visibility of the stimulus, are accustomed to determine the limits of the field

with the white stimulus on the gray arc of the perimeter as background. In view of this practice it may contribute something to the soundness and success of the work in perimetry to show the effect of relation to background on the size and shape of the form field for stimuli of different sizes.

Conditions Under Which the Work Was Done

The fields were taken on the Ferree-Rand perimeter with strict observance of all the precautions prescribed for the use of this perimeter. With this instrument all of the external conditions of the test can be held constant and can be reproduced at will. The intensity of illumination was 7 foot-candles. The stimulus was in every case the white of the Hering series of pigment papers, coefficient of reflection 78 per cent. The determination of the limits was made in all cases with a preexposure of the same brightness as the background on which the stimulus was viewed. In the first series of experiments a preliminary survey was made of the effect of relation of stimulus to background on size of field by using as backgrounds the 30 grays of the new series of Hering gray pigment papers,[1] supplemented in the upper part of the scale of reflection coefficients by two grays from the Munsell series.[2] This survey showed that some of the backgrounds at the lower end of the scale of coefficients of reflection give the same or very nearly the same extent of field when used with the one degree white stimulus. These were discarded and the series of backgrounds finally employed were from dark to light, Numbers 30, 22, 18, 10, 8, 7, 6, 5, 4, 3, and 2 of the Hering series and Numbers 8 and 7 of the Munsell series. The coefficients of reflections of these backgrounds were respectively: 4, 8.5, 11, 19, 22.5, 26, 33, 35, 41, 49, 60, 64, and 69 per cent.

It may be noted that, while the coefficients of reflection in the series are spaced rather widely in the upper part of the scale, the sensation differences represented are small. The white stimulus on a gray background, having a coefficient of reflection of 69 per cent, for example, shows very little difference in sensation from its background in central vision. This difference, however, is sufficiently enhanced in the mid-portion of the peripheral field to give it the subjective value needed in the series. Two reasons may be given for the subjective enhancement of brightness differences in this part of the field: (1) in general, the greater sensitivity to light and to light difference in the paracentral and mid-peripheral field; and (2) particularly the greater sensitivity to brightness induction or contrast in all or the greater part of the peripheral field. The brilliancy with which a white stimulus stands out against its background in peripheral as compared with central vision is a phenomenon that may be noted by any careful observer.

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[1] These papers may be obtained from C. H. Stoelting Co., Chicago.

[2] These papers may be obtained from Universal Color Standards, Inc. Baltimore, Maryland.

In a second series of experiments the effect of variation of relation to background for stimuli of different sizes and, conversely, the effect of variation of size of stimulus for different relations of stimulus to background were determined. Five sizes of stimulus were used: 5.8, 4.4, 2.9, 1.5, and 1.0 mm. At the distance of the arc of the perimeter from the observer's eye, 33 cm., these stimuli subtended visual angles respectively of 1, 0.75, 0.50, 0.25, and 0.17 degrees. Six backgrounds were chosen; the black provided with the perimeter for use with the white stimulus (Hering gray No. 30); a gray of approximately the brightness of the background provided for use with the red and blue stimuli (Hering gray No. 22); a gray of approximately the brightness of the background provided for use with the green stimulus (Hering gray No. 7); a mid-gray of approximately the brightness of the arc of the perimeter (Hering gray No. 10); and two grays lighter than any of these (Hering grays No. 4 and No. 3). The coefficients of reflection of these backgrounds are respectively: 4.0, 8.5, 26.0, 19.0, 41.0, and 49.0 per cent.

Considerable difficulty was experienced in working with the 0.5, 0.25, and 0.17 degree stimuli on the lighter gray backgrounds. Three reasons may be assigned for this difficulty. (*a*) The intermittent visibility which is characteristic of stimuli of small area and small difference from the background in the peripheral field. This is very confusing to the judgment and renders a consistent determination of the limits difficult to make. (*b*) The poor refractive conditions in the peripheral field and the consequent great distortion and blurring of the images of small stimuli. This makes the observation difficult particularly when the stimulus is white and the background is a light gray. And (*c*) the gradual slope of the sensitivity gradient for achromatic stimuli in the mid-periphery of the field. Unlike color stimuli whose sensitivity gradient is steep near the limits of the field, the form stimulus of low visibility is seen faintly near the limits of its field, in fact, in all parts of its field. For it there is no well-marked region of distinct visibility shading abruptly into the background, as there is for colors. A definite demarcation of the limit is, therefore, much more difficult to make. For all of these reasons form stimuli of very low visibility cannot be relied upon to give a satisfactory reproducibility of result. Also, they are not well adapted for use with sick patients whose attention is difficult to hold. When stimuli of this order of visibility are wanted, color stimuli are greatly to be preferred, particularly for the determination of the limits of sensitivity.

The results selected for presentation in this paper were obtained with an observer especially trained in making difficult judgments in the peripheral field. However, to insure that the results obtained are typical, they were checked at critical points by other observers. Further, results obtained with this observer have been abundantly checked for both normalcy and reproducibility through many years.

RESULTS

The results are given in Table 1 and Figures 1-4. In Table 1

TABLE 1

SHOWING THE EFFECT OF VARYING THE BRIGHTNESS OF THE BACKGROUND ON THE SIZE OF THE VISUAL FIELD FOR WHITE STIMULI OF DIFFERENT SIZES

Coefficient of reflection of stimulus 78 per cent. Index of size of field: average breadth of field in the eight principal meridianal quadrants, expressed in degrees.

Serial number of background		Coef. of Refl. of background (per cent)	Difference in coef. of refl. between object and background (per cent)	Average breadth of field for stimuli of				
				1° (degrees)	0.75° (degrees)	0.50° (degrees)	0.25° (degrees)	0.17° (degrees)
Hering	No. 30	4.0	74.0	71.3	70.7	68.6	63.3	57.3
	No. 22	8.5	69.5	70.4	69.5	67.0	60.6	52.8
	No. 18	11.0	67.0	69.6				
	No. 10	19.0	59.0	68.3	67.4	64.2	53.7	43.7
	No. 8	22.5	55.5	67.6				
	No. 7	26.0	52.0	66.9	64.7	60.1	47.9	37.2
	No. 6	33.0	45.0	66.1				
	No. 5	35.0	43.0	65.0				
	No. 4	41.0	37.0	63.0	60.1	51.4	36.1	24.4
	No. 3	49.0	29.0	60.3	56.5	44.8	26.9	16.8
	No. 2	60.0	18.0	55.8				
Munsell	No. 8	64.0	14.0	44.6				
	No. 7	69.0	9.0	28.3				

are given the data on size of field for the various backgrounds for each size of stimulus used. Size of field is expressed in terms of the average breadth of field in the eight principal meridional quadrants, i.e., the average distance of the limit in degrees from the center of the field in these eight quadrants. In Column 1 is given the serial number of the background used; in Column 2, the coefficient of reflection of the background; in Column 3, the difference in coefficient of reflection between stimulus and background; in Columns 4, 5, 6, 7, and 8 the average breadth of field for these backgrounds for stimuli subtending visual angles of 1, 0.75, 0.5, 0.25, and 0.17 degrees, respectively.

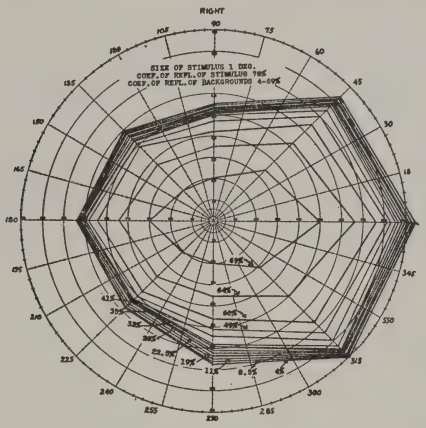

FIGURE 1

Showing the Effect on Size and Shape of the Field for a 1-Degree White Stimulus by Varying the Brightness of the Background

Coefficient of reflection of stimulus, 78 per cent; of backgrounds, 4 to 69 per cent.

In Figure 1 the effect of variation of brightness of background is shown for the 1-degree white stimulus. Thirteen brightnesses of background were used, ranging from 4 per cent to 69 per cent. The coefficients of reflection of these backgrounds are given in Column 2, Table 1. The darkest background was the black which is ordinarily used in the determination of the form field, the lightest was a gray so light that the white stimulus was barely noticeable against it in central vision. It was the purpose of this series of experiments to make a representative determination of the sizes of field that can be obtained with a 1-degree white stimulus by varying its difference in brightness from the background from maximum to minimum, within the limits imposed by 7 foot-candles of illumination and the pigments available for perimetric work.

In Figure 2, *A, B, C,* and *D,* the effect of variation of brightness of background is shown for different sizes of stimulus. Six backgrounds were used (coefficients of reflection, 4, 8.5, 19, 26, 41, and

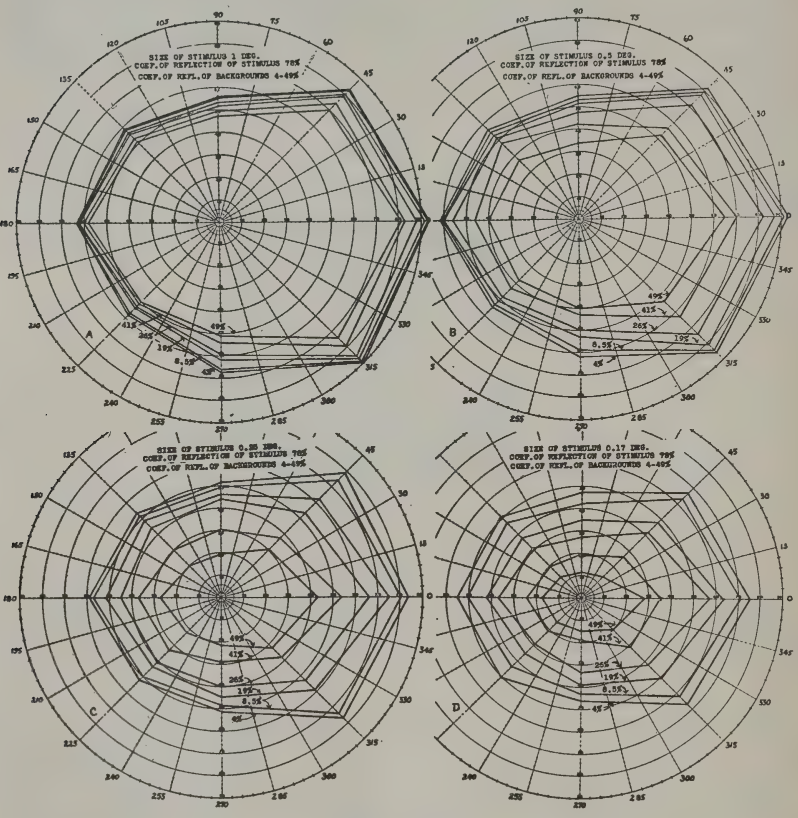

FIGURE 2

Showing the Effect of Variation of Brightness of Background for Different Sizes of Stimulus

Coefficient of reflection of stimulus, 78 per cent; of backgrounds, 4, 8, 19, 26, 41, and 49 per cent, respectively. In Chart A the effect is shown for the 1-degree stimulus; in Chart B, for the 0.5-degree stimulus; in Chart C, for the 0.25-degree stimulus; and in Chart D, for the 0.17-degree stimulus.

49 per cent) for each of the sizes of stimulus, 1, 0.5, 0.25, and 0.17 degrees.

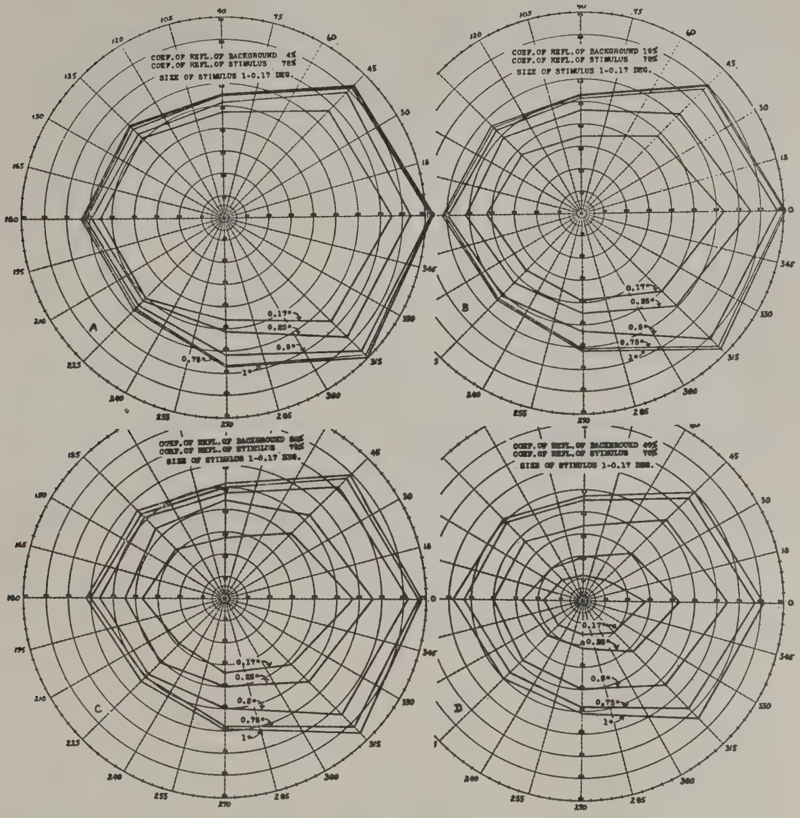

FIGURE 3

Showing the Effect of Variation of Size of Stimulus for Different Backgrounds

Coefficient of reflection of stimulus, 78 per cent; sizes of stimulus, 1, 0.75, 0.5, 0.25, and 0.17 degrees. In Chart A the effect is shown for a background of 4 per cent coefficient of reflection; in Chart B, for a background of 19 per cent; in Chart C, for a background of 26 per cent; and in Chart D, for a background of 49 per cent.

In Figure 3, *A, B, C,* and *D,* the effect of variation of size of stimulus is shown for different backgrounds. For this representation, black, mid-gray, and two lighter grays were selected (coefficients of reflection 4, 19, 26, and 49 per cent, respectively). The sizes of stimulus employed were 1, 0.75, 0.5, 0.25 and 0.17 degrees.

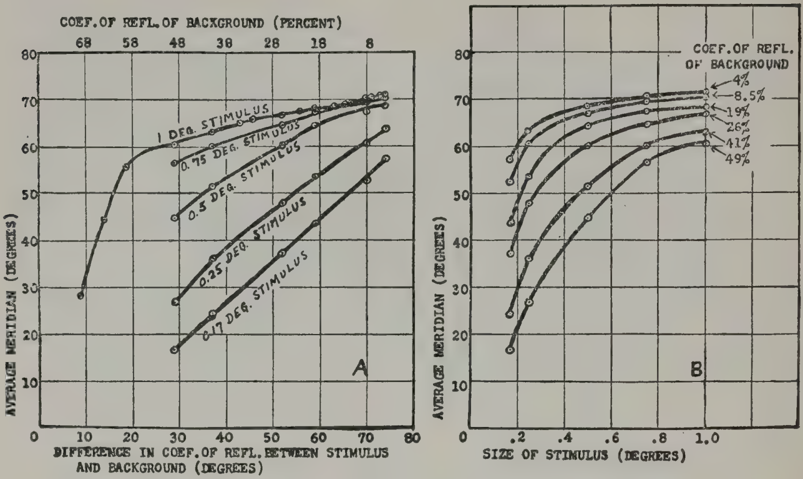

FIGURE 4

Curves Showing the Relationship between Size of Field and the Two Variables: Size of Stimulus and Difference in Coefficient of Reflection between Stimulus and Background

In A the effect of variation of brightness difference between stimulus and background is shown for the different sizes of stimulus used; and in B, the effect of size of stimulus for the different backgrounds.

In Figure 4, *A* and *B,* the relationship between size of field and the two variables, size of stimulus and difference in coefficient of reflection between stimulus and background, is given in the form of curves. As showing more clearly the types and scale of relationship that exists, these curves have considerable theoretical interest. They also have a great deal of practical value in a system of perimetry, as will be discussed later in the paper. In *A* the effect of variation of brightness difference between stimulus and background is shown for the different sizes of stimulus used; that is, curves are given for each of the different sizes of stimulus in which difference from the background (horizontal coordinate) is plotted against size of field (vertical coordinate). In *B* the effect of size of stimulus is shown for the different backgrounds. In this chart curves are given for each of the backgrounds in which size of stimulus (horizontal coordinate) is plotted against size of field (vertical coordinate).

The results shown in Table 1 and Figures 1-4 may be briefly summarized and discussed as follows:

1. Relation of stimulus to background, as one of the cardinal factors determining the visibility of the stimulus, exerts a very important influence on the size and shape of the form field. The influence of this factor is comparable in importance with size of stimulus and intensity of illumination. This fact should be kept clearly in mind in planning the conditions for a perimetric examination. If a white stimulus is to be used on the gray arc of the perimeter or any other gray background for diagnostic purposes, norms must be determined for that condition. The results are not comparable, for example, with those which have been obtained with a white stimulus on a black background, or with norms determined for this latter condition.
2. The influence of difference in brightness from the background is much greater for small than for large stimuli. For the 0.17- and 0.25-degree stimuli there is almost a straight-line relationship between increase in size of field and increase in percentage difference in coefficient of reflection between stimulus and background. For the larger stimuli the effect of the increase is not so great and is less regular. These results, it will be remembered, were obtained with a constant intensity of illumination. What the effect of size of stimulus and relation to background would be when varied separately or together at other intensities of illumination or with an uncontrolled illumination cannot be predicted. In a practice of perimetry in which size of stimulus is the only factor subjected to special provisions for control, considerable confusion as to results must ensue.
3. For the larger stimuli, size of field increases rapidly with increase of brightness difference between stimulus and background near the lower end of the scale. Beyond this the increase is gradual. For the 1- and 0.75-degree stimuli, for example, the knee of the curve is reached with a difference in coefficient of reflection between stimulus and background of only 29 per cent. This represents the difference between the white of the Hering series of pigment papers and gray No. 3, which is very light gray.
4. Similarly, the effect of variation of size of stimulus is much greater for small than for large brightness differences between stimulus and background. For the smallest difference used (29 per cent) the knee of the curve is reached with a stimulus subtending a visual angle between 0.75 degree and 1 degree; for the largest difference (74 per cent) the knee of the curve is reached with a stimulus sub-

tending a visual angle of 0.25 to 0.50 degree. The defective imagery and the low acuity in the peripheral field are doubtless very important factors in the effect of decrease of size of stimulus on the size of the field for the smaller sizes of stimulus. It seems reasonable to infer that defects in imagery exert a stronger tendency to render a small than a large stimulus indistinguishable from the background, and it is certain that low acuity would play an important rôle in the amount of difference from the background that is required for the discrimination of a small stimulus. The results with small stimuli are thus unduly susceptible to errors in refraction and to individual differences in acuity, which is not the type of defect that perimetry is designed to detect.

5. From the fact that so small a cut in the size of the field was obtained by decreasing either the size of the stimulus or the brightness difference between stimulus and background when conditions which give very wide fields were used as the basis on which to determine the amount of cut, it can be inferred that the gradient of achromatic sensitivity is very steep in the extreme peripheral portions of the field. On the other hand, from the fact that a comparatively large cut in the size of the form field was obtained by decreasing either the size of the stimulus or its brightness difference from the background when conditions which gave fields of medium or small size were used as the basis on which to determine the amount of cut, it can be inferred that this gradient is very gradual in the mid-portions of the peripheral field. These inferences as to the shape of the gradient of achromatic sensitivity are in accord with the knowledge that we have of this point on the basis of direct experimental determinations.

It is obvious that the curves in Figure 4 can be made to serve a very useful purpose in the practice of perimetry and scotometry. From these curves it can be very readily determined, for example, just what combination of size of stimulus and relation of stimulus to background is needed when a sensitive examination of some particular region of the field is wanted with a form stimulus. Several cases can be made of this.

1. In scotometry, it can be determined from the curves just what combinations are needed to give stimuli which are at or near the threshold of visibility for any particular zone or region of the retina. This information is very useful in a delicate and careful search for scotomas.

2. In perimetry a test of the functional condition of the retina is made only at or near the points in the field which are called the limits of sensitivity. The curves in Figure 4 show what sizes of field may be expected with different combinations of size of stimulus and relation to background. In testing for pathological conditions which have characteristic regions or locations of disturbance, this knowledge of relation of size of field to various combinations of size of stimulus and relations of stimulus to background is very useful to have in advance of the test. Contraction of the field in incipient optic atrophy, for example, can often be detected with stimuli which give a wide field when it would be missed entirely with stimuli which give a narrow field; a thorough examination for the nasal step in glaucoma requires a series of stimuli that will give limits at suitably spaced intervals from the periphery towards the center, etc.

3. If equivalent form stimuli of different sizes are wanted, the curves in Figure 4 read from left to right from any point on the vertical coordinate show what combinations of stimulus and background are needed to give fields of approximately the same size.

4. The curves in Figure 4 are of great assistance in the selection of form stimuli which give fields of approximately the same size as color stimuli. Among the situations for which this equivalence is of value, the following may be mentioned: (*a*) The experimental determination whether there is a special affinity of the various pathological processes for the color sense. This determination not only sustains an important relation to diagnostic procedure but it should give information of systematic and theoretical importance, i.e., a special susceptibility of the color processes to pathological disturbances is one of the points which have to be taken into account in a decision as to whether there is need for assuming a special physiological process for the explanation of color sensation. It is also of interest in this connection to know whether form and color stimuli, so selected as to give equal limits in one meridian, will give equal or approximately equal limits in all meridians. Such a constancy of relation in the distribution of form and color sensitivity over the retina has in itself a probable bearing on the decision as to whether an assumption of separate physiological processes is needed for the explanation of color. (*b*) The examination or study of the visual field for eyes which are color-blind. And (*c*) any type of examination or study where preference is for a form rather than a color stimulus. With reference to the equivalence of form and color stimuli it may

be noted that for the observer whose results are given in this paper, the field for blue averages 42 degrees in the eight principal meridional quadrants; for red 40 degrees; and for green 23.3 degrees. For the same observer form fields averaging between 40 degrees and 45 degrees are given by 1 degree white on gray, coefficient of reflection 64 per cent; 0.5 degree white on gray, coefficient of reflection 49 per cent; and 0.17 degree white on gray, coefficient of reflection 19 per cent. Of these the 0.5 degree white stimulus on gray, coefficient of reflection 49 per cent, is the most feasible and practical to use when a form stimulus is wanted which will give a field approximating in size the fields for 1 degree red and 1 degree blue on backgrounds of gray of the brightness of the color. The reasons for this selection are that the 0.5-degree stimulus is sufficiently large to be outside the class of acuity objects and the background is not too light to be entirely impracticable for use.

We are at present making a comparison of the fields obtained for a number of observers with this stimulus and background with those obtained with 1 degree red and blue on gray backgrounds of the brightness of the color. So far, our results show that the size of field given by the three stimuli is nearly the same for any non-pathologic eye. The results for pathologic eyes do not as yet warrant even a tentative conclusion. As stated earlier in the paper, however, our chief interest in making the comparison was to determine whether the great sensitivity of color stimuli for detecting pathological disturbances is due solely to their low visibility or whether there is, in addition, a special susceptibility of the color sense to pathological influences. The possibility of finding a form stimulus which could be uniformly substituted for color stimuli in practical perimetry was not an important incentive to the comparison. Even if it can be shown, for example, that a 0.5-degree white stimulus on a light gray background (coefficient of reflection 49 per cent) has as great sensitivity for the detection of pathological disturbances as 1 degree red and 1 degree blue, its substitution for the color stimuli in practical work for other than color-blind eyes could not be recommended on the grounds of feasibility. Because of the small size of the stimulus, the lightness of the background, and the very small difference in brightness between stimulus and background, this combination, which was selected as the most feasible of those giving approximately the same size of field as the color stimuli, is much more difficult to use, much more trying for the patient to observe, gives a poorer reproducibility of result, and is much harder to keep in condition for use than the color stimuli. In planning a series of stimuli graded as to visibility, for example, the recommended procedure is that form stimuli be used only until the level of visibility of the color stimuli is reached. Beyond this point the color stimuli are not only more feasible and convenient to use, but there is, in addition, a strong probability of a special and perhaps differential susceptibility to pathological disturbances.

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DEUX FACTEURS IMPORTANTS DE LA GRANDEUR ET DE LA FORME DU CHAMP DE FORMES ET QUELQUES-UNES DE LEURS RELATIONS AVEC LA PERIMÉTRIE PRATIQUE

(Résumé)

Les facteurs étudiés sont la grandeur du stimulus et la relation du stimulus au fond. On a employé cinq grandeurs du stimulus et treize relations au fond. On montre (*a*) que la grandeur du stimulus et sa relation au fond, comme facteurs principaux qui déterminent la visibilité des objets, exercent un effet très important sur la grandeur et la forme du champ de formes (*b*) que l'influence de la différence de clarté du fond est beaucoup plus grande pour les petits stimuli que pour les grands; (*c*) que pour les plus petits stimuli il y a une relation presque linéaire entre la grandeur du champ et la relation au fond, tandis que pour les plus grands stimuli l'accroissement est plus rapide près de l'extrémité la moins élevée de l'échelle; (*d*) que l'effet de la variation de la grandeur du stimulus est beaucoup plus grand pour les petites différences que pour les grandes entre le stimulus et le fond; et (*e*) que le grandient de la sensibilité achromatique s'élève très rapidement dans les dernières portions périphériques du champ.

Les courbes faites pour montrer la relation entre la grandeur du champ et ces deux facteurs peut servir un but très utile dans les applications pratiques de la périmétrie. (1) Dans la scotométrie on peut déterminer le grandeur des champs qu'on peut examiner avec des stimuli de divers degrés de visibilité. Ces renseignements sont très utiles quand on cherche délicatement et soigneusement des scotomes. (2) Les courbes indiquent la position des limites qu'on peut attendre avec diverses combinaisons de la

grandeur du stimulus et la relation au fond. En cherchant des conditions pathologiques par la périmétrie lesquelles ont des régions caractéristiques ou sites de dérangement, ces renseignements sont très utiles avant la recherche. (3) Si l'on désire des équivalents de forme de différentes grandeurs, les courbes montrent les combinaisons du stimulus et du fond qu'il faut pour donner des champs d'environ la même grandeur. (4) Les courbes aident beaucoup dans le choix des stimuli de forme qui donnent des champs d'environ la même grandeur que les stimuli de couleurs.

Ferree et Rand

ZWEI WICHTIGE BESTANDTEILE DER GRÖSSE UND DER GESTALTUNG DES FORMFELDES, UND EINIGE IHRER ZUSAMMENHÄNGE MIT DER PRAKTISCHEN PERIMETRIE

(Referat)

Die untersuchten Einwirkungen waren die Grösse des Reizes und das Verhältnis des Reizes zum Hintergrund. Es wurden 5 Reizgrössen und 13 verschiedene Verhältnisse zum Hintergrund gebraucht. Es wird erwiesen: (*a*) dass, als Hauptfaktore bei der Bestimmung der Sichtbarkeit von Gegenständen, die Grösse des Reizes und das Verhältnis zum Hintergrund auf die Grösse und Gestaltung des Formfeldes eine sehr wichtige Einwirkung ausüben; (*b*) dass der Einfluss der Verschiedenheit vom Hintergrund in Bezug auf Helligkeit bei kleinen Reizen viel stärker ist als bei grossen; (*c*) dass bei den kleineren Reizen fast ein lineales Verhältnis besteht zwischen der Grösse des Feldes und dem Verhältnis zum Hintergrund, während bei den grösseren Reizen die Zunahme in der Nähe des niedrigen Endes der Skala viel rascher stattfindet; (d) dass die Wirkung der Variation der Grösse des Reizes bei kleinen Unterschieden zwischen Reiz und Hintergrund viel stärker ist als bei grossen; und (*e*) dass der Gradient der akromatischen Empfindsamkeit in den extrem peripheralen Teilen des Feldes ein sehr steiler ist.

Die Kurven, die entworfen worden sind um die Beziehung zwischen der Grösse des Feldes und diesen beiden Einwirkungen darzustellen können in den praktischen Anwendungen der Perimetrie gut benutzt werden. (1) In der Skotometrie kann bestimmt werden, welche Feldgrössen mit verschiedenen Graden der Sichtbarkeit untersucht werden können. Diese Auskunft ist bei einer genauen und sorgfältigen Forschung nach Skotomen sehr nützlich. (2) Die Kurven zeigen an, welche Lage der Grenzen (location of limits) bei verschiedenen Kombinationen von Reizgrösse und Verhältnis zum Hintergrund zu erwarten sind. Bei der Forschung mit Perimetrie nach pathologischen Zuständen denen karakteristische Gebiete oder Lagen der Störung eigen sind, ist diese Auskunft vor der Prüfung sehr nützlich. (3) Bedarf man gleichwertiger Formreizen von verschiedenen Grössen, so zeigen die Kurven an, welche Kombinationen von Reiz und Hintergrund man gebrauchen muss um Felder von ungefähr gleicher Grösse zu erhalten. (4) Die Kurven sind bei der Auswählung von Formreizen, welche Felder von ungefähr der selben Grösse wie die mit Farbenreizen erhaltenen leifern, sehr dienstbar.

Ferree und Rand

THE EFFECT OF HYPNOSIS ON LONG-DELAYED RECALL*[1]

From the Psychological Laboratory of Purdue University

John M. Stalnaker and Edward E. Riddle

There is a belief of long standing that hypermnesia (improved memory) can be induced by hypnosis. Moll, writing in 1890, however, says, "As far as I know no careful investigations have yet been made of this point." Nor, as far as the writers know, have any careful investigations been made since that time, until last year when one carefully controlled experimental study by Miss Huse, carried out under the direction of Professor Clark L. Hull, was reported.

Material related to the problem of improved memory due to hypnosis may be considered in three categories. In the first place, we have a certain amount of authentic evidence which establishes the fact that hypnosis may be successfully used in recalling certain lost memories when the events have been associated with traumas of a somatic, or emotional, nature. It is reported, for example, that a student who was taking a friend for a drive raced a train to a crossing.[2] The automobile was struck, the boy thrown out and knocked unconscious. He was found to be uninjured except for minor bruises and scratches. On regaining consciousness, he had no recollection of the accident. His last memory was of driving to his friend's home. All efforts to make him recall the accident proved futile. In a hypnotic trance, however, the complete details of the incident from the time when he reached his friend's home until the train struck the car were recalled. Reports of similar cases are available in the literature.

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*Recommended for publication by Clark L. Hull, accepted by Carl Murchison of the Editorial Board, and received in the Editorial Office, November 12, 1931.

[1] This study was undertaken at the suggestion of Clark L. Hull, and has profited by his criticism. T. G. Thurstone's suggestions as to statistical treatment of the data have been valuable. J. M. Stalnaker arranged and is responsible for the details of the experimental procedure, acted as operator for 7 subjects, and handled the interpretations of the data. E. E. Riddle acted as operator for 5 subjects.

[2] From an unpublished report by C. L. Hull.

A second type of attack is considered by Miss Huse (2) in a paper reported in *The Journal of Experimental Psychology* for 1930. Her subjects learned nonsense material in the waking state and, after a lapse of 24 hours, recalled the material in the waking and the trance states. Her data show slightly more recall in the normal state than in the trance. "There is probably no significant difference," she concludes, "between recall in the trance, and normal states of nonsense material 24 hours after learning."[3]

A third possibility of memory improvement is in the recall of meaningful material learned thoroughly but a considerable length of time previous to the recall. It is this type of recall with which this paper is concerned.

Twelve men were used as subjects in this experiment. They were all students in the University and were deep-trance subjects, that is, they showed negative hallucinations, analgesia, catalepsy, automatic writing, etc. The trance was originally induced by optical fixation, but, after the subjects became more familiar with the conditions, verbal suggestion methods were used.

The subjects volunteered for this work because of their interest in hypnosis. They knew nothing of the nature of the experiment at the outset, but they soon learned that it had to do with memory. In no case did the subject appear to put forth any effort to find out what was being done. The attitude was that something was being done for "science" and that, by acting as subjects, they would probably learn something about hypnotism.

Those who proved to be good hypnotic subjects were asked if they would be willing to report for eight periods for an experiment. The ones who accepted were scheduled for their first experimental period, at which they were asked to name selections of any type of material which they had learned a year or more ago. The experimenter made suggestions of common selections if they did not readily recall the names of at least eight selections. No selection was listed unless the subject was certain that he had memorized it. Specific instructions were given that the purpose of the experimental work would be defeated if the subject were to relearn or even reread any of these selections. As the subjects were busy engineering students, with ample work to do, there was no temptation for them to do this. It was assumed that the subjects did not make any attempt to study their selections.

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[3] The Huse study has been criticized on the ground that the nonsense memory material which she employed must have been relatively neutral as compared with the memory material involved in psychopathic amnesias (1). The injustice of the criticism lies in the fact that Huse was investigating merely the hypnotic threshold of recall of neutral memory material. The question of hypnotic memories for strongly emotional materials under experimental conditions remains, of course, to be investigated.

Half of the subjects were started in the experiment with the waking state first, while half were started with the trance state first. In the waking experimental period the subject was directed as follows:

> "You said that you had memorized at some time in the past 'The Village Blacksmith.' Now I want you to take this pencil and paper and write out this selection just exactly as you memorized it. Write as much of it as you can. When you have done your very best bring me the paper."

In the trance state the following directions were read to the subject after the operator believed the subject was at his usual depth of trance:

> "I want you to think back to the time when you memorized 'The Village Blacksmith.' You can remember exactly when you learned it. It comes back to your mind. You can remember the piece vividly, without any strain or worry.
>
> "I am going to give you a pad of paper which I want you to hold in your left hand, and when I put the pencil in your right hand you will find you can open your eyes. Then you will write the piece just as you memorized it. As soon as you have completed writing as much as you can remember of the selection you will put the pencil down, your eyes will again become heavy as they are now, and you will rest just as you now are resting. Remember, even when your eyes are opened you will remain in just the state you are now in."

After the subject had finished the writing in the trance state, the suggestion was made that he would wake up quickly and completely, feel well, enjoy being a subject, etc. The awakening was always carried on in the same manner, by slowly counting to ten, the subject having been told to be wide awake at ten.

In subsequent experimental periods the subjects were asked to recall first in the trance and second in the waking, or vice versa, the various selections at the rate of one selection at each experimental period. The double-fatigue order was used. If the first period started with the trance, the second and third periods started with the waking, and the fourth with the trance. That is, the A-B-B-A order was used to equalize the practice effect in the two conditions.

The subjects readily understood these directions. They appeared to be interested in the experiment and, as far as observation goes, they seemed to put forth a great deal of effort in the waking state. Sometimes in the waking state they would think for as long as ten minutes, trying to recall certain lines. Seriousness of purpose was apparent with all of the subjects.

The twelve subjects reported for a total of 92 experimental periods. This means that 92 selections were recalled, and that there were 92 trance sessions either followed or preceded by 92 waking sessions. When the waking period followed the trance, the suggestion was given as described above that the subject would awake from the trance very quickly and that he would be wide awake. A short interval of time between waking from the trance and the waking session was allowed. The subjects appeared to be wide awake.

The papers were scored quantitatively by checking them with the original sources and allowing one point for each word correctly recalled. Spelling errors were ignored. Among the 92 selections there were five cases of reversal involving three subjects, i.e., cases in which the subject recalled more in the waking than in the trance state. (See Table 1: Subject 1, Trial 1; Subject 7, Trial 2; Subject 11, Trials 2, 3, and 7.) Large individual differences are to be noted. Even the same subjects show considerable variation for different selections, as might be expected. The median percentage gain in the trance state for the 92 selections is 38.5. The quartiles are 7.7% and 94.7%.

The fact of only five reversals, together with the large median percentage gain, indicates clearly that under the conditions of the experiment the trance state proved more conducive to recall of remote events. Data of this nature lend themselves to numerous kinds of statistical manipulation, the results of most of which are misleading. Subject Number 1, for example, recalled seven selections. (See Table 1.) His percentage gains per selections are: —12.4 (89), 3100.0 (1), 144.0 (50), 0.0 (95), 20.0 (20), 19.0 (18), and 30.1 (51). The numbers in the parentheses indicate the number of words recalled in the waking state, and constitute the base for calculating the percentage. The median percentage trance gain here is 20.0%. His mean percentage trance gain is 471.5%. If, however, the total recall in the waking state for all the seven periods is summed and compared with his total recall in the trance state, the gain

TABLE OF RAW DATA (TABLE 1)

The Figures Indicate the Number of Words of the Given Selection Which Were Correctly Written

Subjects by J.M.S.							Subjects by E.E.R.						
Subject number	Trial number	Waking first	Trance second	Trance first	Waking second	Difference	Subject number	Trial number	Waking first	Trance second	Trance first	Waking second	Difference
1	1			78	89	—11		7			62	47	15
	2	1	32			31		8	39	114			75
	3	50	122			72							
	4			95	95	0	6	1	27	89			62
	5	20	24			4		2			48	7	41
	6			21	18	3		3			20	10	10
	7			73	51	22		4	36	94			58
								5			16	0	16
								6	7	35			28
2	1	24	27			3		7	12	43			31
	2			42	27	15		8			75	18	57
	3			57	30	27							
	4	65	69			4	7	1	55	67			12
	5			2	1	1		2			34	36	—2
	6	26	65			39		3			23	17	6
	7	23	47			24		4	18	36			18
	8			21	0	21							
	9	33	52			19	8	1	17	20			3
								2			18	18	0
3	1			87	63	24		3			57	51	6
	2	25	48			23		4	30	43			13
	3	25	26			1		5			14	13	1
	4			11	8	3		6	14	17			3
	5	46	53			7		7	37	73			36
	6			25	18	7		8			11	7	4
	7			52	47	5							
	8	48	50			2	9	1	48	145			97
								2			17	17	0
4	1	30	42			12		3			8	8	0
	2			15	14	1		4	9	11			2
	3			4	4	0		5			21	14	7
	4	19	20			1		6	4	4			0
	5			22	22	0		7	37	79			42
	6	38	39			1		8			88	53	35
	7	15	25			10							
	8			16	13	3	10	1			29	27	2
								2	35	66			31
5	1			66	49	17		3	67	69			2
	2	30	55			25		4			41	26	15
	3	14	26			12		5	13	14			1
	4			14	13	1		6			21	16	5
	5	37	62			25		7			67	43	24
	6			20	17	3		8	56	82			26

TABLE OF RAW DATA (TABLE 1) (*continued*)

THE FIGURES INDICATE THE NUMBER OF WORDS OF THE GIVEN SELECTION WHICH WERE CORRECTLY WRITTEN

Subjects by J.M.S.							Subjects by E.E.R.						
Subject number	Trial number	Waking first	Trance second	Trance first	Waking second	Differ-ence	Subject number	Trial number	Waking first	Trance second	Trance first	Waking second	Differ-ence
11	1			239	132	107		7	4	13			9
	2	25	24			—1		8			8	8	0
	3	167	159			—8							
	4			16	9	7							
	5	17	19			2							
	6			78	78	0							
	7			25	27	—2							
	8	9	41			32							
12	1	27	51			24							
	2			19	16	3							
	3			55	24	31							
	4	9	14			5							
	5			19	9	10							
	6	13	14			1							
							Grand total		1401	2320	1850	1310	1459

is 37.3%. On the average he gained either 20.0%, 37.3%, or 471.5%, according to the method of calculation of the average. Such variations are found for all subjects. Again, when the results of all subjects are combined, a variety of figures may be secured according to the method of combination used. The mean percentage of the mean gain per subject (using the selection as the unit) is 66.8% when *n* is taken as 92, the number of selections; taking *n* as the number of subjects, and ignoring the fact that some subjects appeared for only 4 selections while others appeared for 9, the mean percentage gain is 64.9. If the total words recalled are used as the unit, the gain is 53.7% of the total waking recall.

Regardless of the method of computation used, however, it is obvious that there is a significant advantage of the trance state. Table 1 gives the basic raw data in the original form. All computations, of course, are based on various combinations of these figures. An examination of this table shows the large individual variation (cf. Subject 6 and Subject 4) as well as the general superiority of the trance condition.

TABLE 2

SUMMARY BY SUBJECTS OF THE EXPERIMENTAL RESULTS

The gain in recall during the trance is expressed as a percentage of the amount recalled in the waking state.

Subject	No. of experimental periods	Total waking recall	Total trance recall	Trance gain	Percentage trance gain
1	7	324	445	121	37.3%
2	9	229	382	153	66.8
3	8	280	352	72	25.7
4	8	155	183	28	18.1
5	8	246	419	173	70.3
6	8	117	420	303	259.0
7	4	126	160	34	27.0
8	8	187	253	66	35.3
9	8	190	373	183	96.0
10	8	283	389	106	37.5
11	8	464	601	137	29.5
12	8	110	193	83	75.5
Total	92	2,711	4,170	1,459	778.3
Mean					64.86%

Table 2 gives the summary of the data of Table 1, when arranged by totals per subject, and when the order (T-W or W-T) of experimentation is ignored. Here again is to be noted a large individual variation. The difference between the total waking recall and the total trance recall is statistically significant, regardless of the method of computation used. The method of computation, which tends to minimize the differences, gives a critical ratio of 5.3 indicating that the chances are over 1340 to 1 that this difference is a true one.

As verbal recall amnesia exists for trance events in the waking state, and as there is no amnesia for waking events in the trance state, the experimental order of W-T ought to be superior to that of T-W. Mr. Strickler (3), in investigating this point, found that by the relearning method for good trance subjects apparent amnesia to the extent of about 80% is found when corrections for controls are made. He used nonsense material. Likewise Miss Huse (2, p. 526) also notes this tendency. The data of the experiment here reported tend to illustrate the same effect. In the order W-T a total of 1401 correct words were recalled in the waking state, and 2320 in the trance. (See *Grand total,* Table 1.) This gain of 65.6% of the trance is greater than the 41.2% gain of the trance condition over the waking when the reverse order is used—trance first and waking second. This establishes further that there is a real amnesia for trance events. The counterbalanced order of experimentation which was used should offset this effect and prevent it from distorting the final results.

Amnesia, however, is never complete. Some memory of trance events does carry over into the waking. Hence the second condition, whether waking or trance, should show some practice effect, some gain over the first condition. Table 3 shows the data arranged in this fashion. It may be seen that on the average there is a gain of 14.68% due to this practice effect. Here again, however, the counterbalanced order of experimental periods does not permit this to influence the final results.

A number of interesting qualitative results were discovered in examining the written material. For example, the subjects in the

TABLE 3

THE INCREASE IN THE AMOUNT OF RECALL (PRACTICE EFFECT) FOUND IN THE SECOND EXPERIMENTAL CONDITION OVER THE FIRST

The same number of hypnotic and waking periods occur in each condition. Every selection is recalled in both the first and the second condition.

Subject	No. of experimental periods	First condition	Second condition	Gain of second condition	Percentage gain
1	7	338	431	93	27.5%
2	9	293	318	25	8.53
3	8	319	313	—6	—1.88
4	8	159	179	20	12.6
5	8	282	383	101	35.8
6	8	241	296	55	22.8
7	4	130	156	26	20.0
8	8	198	242	44	22.2
9	8	232	331	99	42.7
10	8	329	343	14	4.26
11	8	576	489	—87	—15.1
12	8	154	149	—5	—3.25
Total	92	3,251	3,630	379	176.16
Mean					14.68%

trance state attempted to reconstruct the poetry which they were unable to recall literally. For the second stanza of "The Village Blacksmith," one subject composed:

The smithy whistles at his forge
As he shapes the iron band;
The smith is very happy
As he owes not any man.

In the waking state he omitted this stanza entirely.

A second illustration is found in the recall of another selection by Longfellow, "The Song and the Arrow." After the subject in the trance had recalled the first two lines approximately correctly, he started improvising where his memory proved inadequate. The final trance version reads:

I shot an arrow into the air
It fell to earth I know not where,
And I forgot that this was shot that day,
And picked myself up and went away.

I breathed a song into the air,
It fell on ears I knew not where.

As I was wandering far and wide,
I heard the Song,
And as I came to a might oak,
I found the arrow still unbroke.

In the previous waking state the subject had written simply:

An arrow and song went into the sky,
I know not why.

Another subject, in recalling the same selection, wrote while in the trance:

I shot an arrow into the air,
It fell to the earth, I know not where,

I sang a song into the skies,
It fell on earth where it dies.

The subject then paused, apparently thinking, and, in a last desperate struggle, wrote while still in the trance:

My only hope as I sit, is to say,
That I shall find them both some day.

He then laid his pencil down, signifying that there was nothing more to be recalled.

One subject during the trance was recalling the ten commandments, which he apparently had been forced to memorize. College life must have affected his earlier moral training, for, after having written six of the commandments, he crossed them out with a sweeping gesture and wrote, "I do not want to remember and I have tried to forget," and laid his pencil down. He had finished. When the experimenter asked him, while the subject was still in the trance, why he had done this, he explained that the commandments told one not to do everything that he wanted to do. The experimenter explained to him that in this work he might recall these without thinking of their meaning. The subject then proceeded to write the remaining commandments. Upon awakening he remembered nothing of this interlude and recalled the commandments in a normal fashion, although not as completely as he had in the trance state. This was the only case in which the subject in the trance state was asked to continue after he had ceased writing.

Another subject, a licensed aeroplane pilot of some skill, recalled in the trance the Preamble to the Constitution. Upon awakening he asked if people dream in trances. He said he could remember dreaming about a grade school teacher whom he hated. Further questioning brought out the fact that he had learned the Preamble to the Constitution under this teacher.

These results may appear at first glance to be in direct opposition to those obtained by Miss Huse, who concludes that there "Is no basis for the popular belief that faint memory traces mediate recall better in the trance than in the normal state." There are certain differences in experimental procedure to be noted. In the present experiment the directions to the subjects in the trance state were not exactly the same as those given in the waking state. In the trance state the subjects were told that they would be able to recall the passage easily. This suggestion was not given in the waking state and may be responsible for some of the apparent influence of the trance. It is not, however, the opinion of the experimenters that this is an important factor, though this is a matter for experimentation, and not for opinion.

A theory quite prevalent is that hypnosis is of value in removing emotional blocking, and that accordingly it will aid in recall only if the normal recall is blocked by emotions. Assuming this theory, without demanding a more rigorous statement or definition of terms, it is probably true that nonsense material learned under laboratory conditions would have a minimum of emotional concomitants. The case would be very different in considering selections of poetry learned in former school days. Thus another explanation of the variations between these two experimental results is found.

If, as is believed by many hypnotists, the trance state removes many ordinary inhibitions, makes the subject less bound by convention and freer, then such freedom would probably be more effective in aiding in the recall of sense rhyme material than nonsense symbolic material. For example, it was found in this experiment that the subjects wrote more of both correct and incorrect words in the trance state than in the waking. They apparently wrote more easily, and as has been mentioned above, they also improvised more freely. This may offer another explanation of the reason why sense material would be more subject to trance hypermnesia than nonsense material.

The experiment herein reported shows that, for 12 subjects recalling 92 selections, hypermnesia in the trance for sense material learned a year or more before has been clearly established. The directions given the subjects in the trance state contained a suggestion as to improved recall, which, apart from the trance, might be responsible for the difference. The subjects were found to improvise the poetry where their literal memory failed to a greater extent in the trance state. Possible explanations of the apparent reversal of the results obtained by Miss Huse are suggested.

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L'EFFET DE L'HYPNOSE SUR LE RAPPEL TRÈS RETARDÉ

(Résumé)

Douze sujets en se rappelant 92 morceaux de prose ou de poésie appris un an ou plus auparavant, ont pu reproduire en moyenne 67 pour cent de plus dans la transe que dans l'état de réveil, établissant ainsi l'hypermnésie pour ce type de chose dans l'état de transe. Les directions données aux sujets dans l'état de transe contenaient une suggestion sur un meilleur rappel,

laquelle, à part la transe, pourraient être en partie responsables des grandes différences obtenues. On a trouvé un effet de pratique de 14 pour cent, l'accroissement du second état sur le premier, bien qu'un ordre contrebalancé a empêché celui-ci d'influer sur les résultats finals. On a trouvé que les sujets ont improvisé la poésie où leur mémoire n'a pas suffi, plus souvent dans l'état de transe. On suggère des explications possibles de la différence de ces résultats en apparence de ceux obtenus par d'autres investigateurs.

Stalnaker et Riddle

DIE EINWIRKUNG DER HYPNOSE AUF LANG-VERZÖGERTE WIEDERHOLUNG (LONG-DELAYED RECALL)

(Referat)

Bei der Wiederholung von 92 Dichtungen und Prosaauszügen gelang es 12 Versuchspersonen im Durchschnitt 67 0/0 mehr Stoff unter Hypnose als wachend zu wiederholen. Es wurde also für diese Stoffart in hypnotischem Zustande (trance) Hypermnesie festgestellt. Die Anweisungen, die der Versuchsperson im hypnotischen Zustande gegeben wurden, enthielten eine Suggerierung verbesserter Wiederholung. Diese Suggestion dürfte vielleicht, von dem hypnotischen Zustande abgesehen, für die grossen Unterschiede die erhalten wurden mit verantwortlich sein. Es zeigte sich eine Einwirkung der Einübung darin, dass die Befunde im zweiten Zustande mit 14 0/0 höher waren, als im ersten, obwohl eine ausgleichende (counterbalanced) Anordnung eine Beeinflussung der endgültigen Befunde durch diese Tatsache verhinderte Man fand, dass die Versuchspersonen im hypnotischen Zustand öfter als im wachenden die Stellen der Dichtung improvisierten woran sich ihr Gedächtnis al ungenügend erwies. Es werden verschiedene mögliche Erklärungen der augenscheinlichen Unterschiede Zwischen diesen Befunden und den von anderen Forschern erhaltenen vorgeschlagen.

Stalnaker und Riddle

SHORT ARTICLES AND NOTES

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THE GEOTROPIC CONDUCT OF YOUNG KITTENS

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A general law governing geotropic orientation has been shown to hold over a range of diverse animal forms.[1] Comparative studies on both vertebrates and invertebrates show that θ, the angle of upward orientation, increases with sin α, where α is the slope of the creeping surface. Equations derived for the exact form of this relationship in different cases describe the behavior of negatively geotropic creeping organisms on inclined planes.

The following experiment conducted on the very young cat sought to discover whether the same type of relationship held for this mammal. Six young kittens, four days old, were tested on an inclined plane and were found to be negatively geotropic. Of these the three most vigorous creepers were selected for the experiment.

The apparatus consisted of a plane surface 4 by 3 feet, hinged at the base and covered with a coarse wire-mesh screen which afforded the animals a secure foothold. The plane was ruled off in 6-inch squares, and by a cord and pulley arrangement could be adjusted to any desired inclination. A protractor fastened to the side gave the angular inclinations. A 25-watt red mazda lamp furnished illumination. This lamp was placed about three feet behind the plane with the light reflected against the back wall of the room. This gave an indirect lighting effect which after a few minutes of dark-adaptation just enabled the observer to perceive the creeping animal. A long pointer was used as an aid in recording the orientation trails. This pointer was held parallel to the longitudinal axis of the creeping body and the corresponding coordinate points at the plane's edges were noted. These points were then recorded on ruled coordinate paper which duplicated the coordinates of the plane. The data sheets, placed on a glass-topped box, were illuminated from below by a small red lamp set inside the box.

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[1] *Cf.* Crozier and Pincus, Pincus, Pincus and Crozier, Crozier and Oxnard, Keeler, Wolf, Wolf and Crozier, Crozier and Stier, Kropp and Crozier, Kropp, Crozier and Stier, Hoagland, and Upton.

The initial behavior of the kittens on the inclined plane was dependent upon the slope of the surface. At low angles of inclination (below $\alpha = 35$ degrees) the creeping was slow, the trails were short, and few in number per unit time. When the slope of the plane was made greater than 35 degrees there occurred a definite change in geotropic conduct. The latent period for initiation of geotropic response decreased, the rate of creeping increased, and the trails became longer and more frequent. The animals were geonegative at all angles above $\alpha = 37$ degrees. Below this inclination some of the trails were geopositive. The downward creeping at these low angles, however, was very slow and indiscriminate, being made up for the most part of short, unoriented, slipping movements. Because of the extreme variability of θ at 30 and at 35 degrees, in contradistinction to its relative stability at 40 degrees, the intermediate angles were tested for a threshold value. This was found to occur at about 37 degrees. At this point the gravitational component becomes effective in controlling the animals' upward movement. As the maximal usable slope was 65 degrees, the geotropic range within which orientation is distinctly modified by gravity is smaller for the cat (at this age) than for other mammals tested.[2]

Table 1 shows the relation of the angular orientation θ, to α, the slope of the plane. The probable errors for each value of θ are listed in the third column. Each value for θ, at 30, 40, 50, 55, 60, and 65 degrees'

TABLE 1

Slope of surface α (degrees)	Angle of orientation θ (degrees)	*P.E.* (degrees)	
30	65	±1.8	(The *P.E.*'s are all based on 20 observations.)
35	64.1	±1.1	
37	73.4	±0.60	
39	77.9	±0.33	
40	79.5	±0.43	
45	81.1	±0.17	
50	83.2	±0.30	
55	84.3	±0.25	
60	85.5	±0.28	
65	88.9	±0.09	

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[2] It is possible, however, that age may have vitiated any precise geonegative orientation at these low angles. The animals were over a week and a half old when tested at angles $\alpha = 30$ and 35 degrees. An investigation now being conducted on kittens one day old shows geonegative orientation at angles below $\alpha = 30$ degrees.

inclination of surface is the mean of 30 observations. At 35, 37, 39, and 45 degrees of slope, θ is the mean of but 20 observations. (One of the kittens became somewhat sluggish and remained motionless on the plane for such long intervals that it was necessary to discard him.)

Observation of the geotropic behavior of young rats and mice has shown that when θ, the angle of orientation, is plotted against log sin α, the

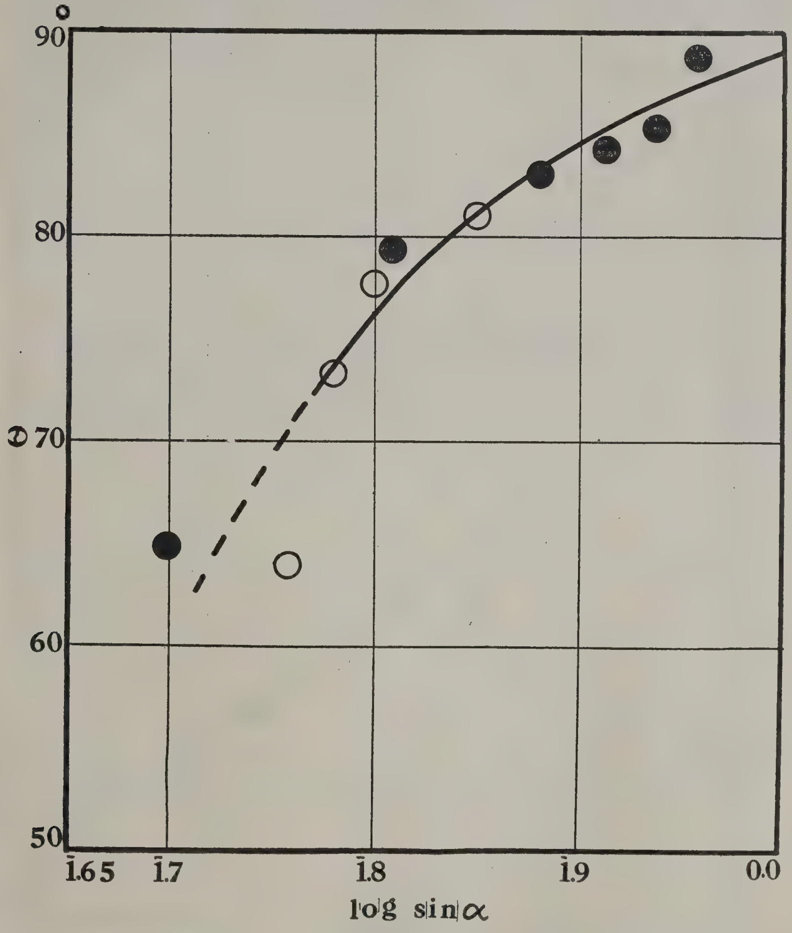

FIGURE 1

θ is represented as a function of log sin α. The black dots represent the means of 30 observations, the white, the means of 20 observations.

approximately rectilinear relationship obtained is in fact definitely sigmoid in character (2, 3). Figure 1 presents the relationship between θ and log sin *a* as found for the cat. The curve may be interpreted as the top of a long drawn out *S* curve. It was impossible to obtain points for the lower regions of the curve, since the minimal threshold value for these animals fell at 37 degrees. However, since the relationship between cos θ and sin *a* (Figure 2) is of the same sort as that found for rats, mice, and guinea pigs (2, 3, 11), it is legitimate to assume that the θ—log sin *a* relationship

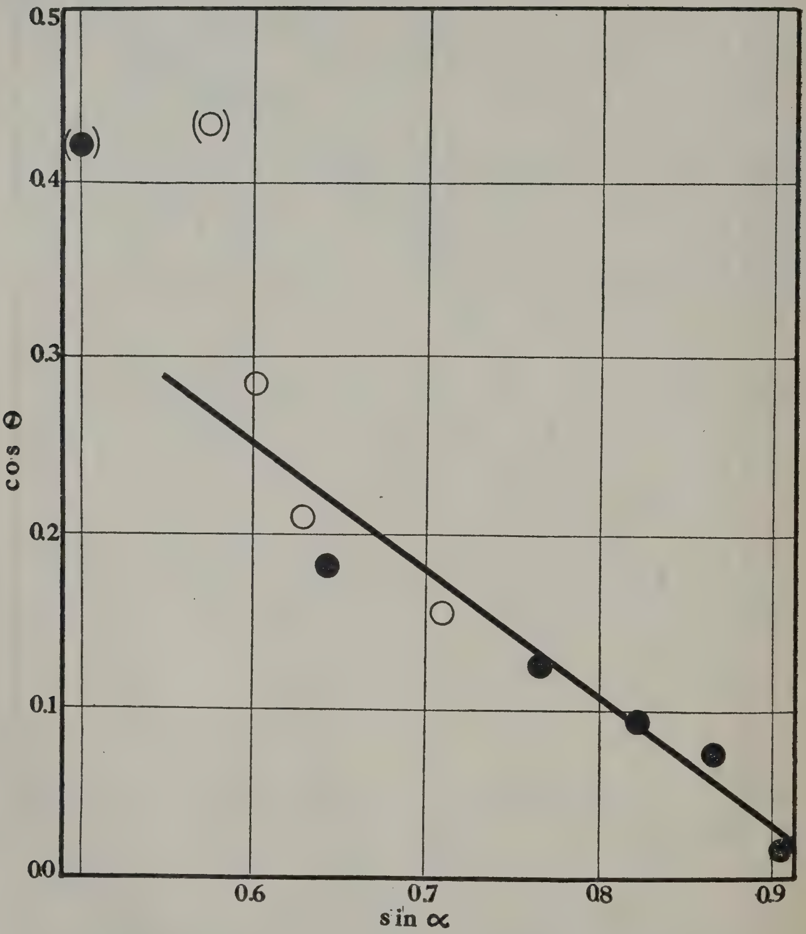

FIGURE 2
The cosine of θ is directly proportional to the sine of *a*.

may also hold for the cat, with limitations such as have been recognized (2, 3). The two points ($\alpha = 30$ and $\alpha = 35$ degrees) in the lower region were disregarded in drawing the curves since both fell below the reliable threshold value. (The trails recorded here gave a multi-modal distribution and large probable errors [Table 1]. At angles above $\alpha = 37$ degrees, the distribution was distinctly monomodal.) At these low values of α, the intensity of geotropic stimulation is opposed by other stimuli that are to a certain extent equipotent. Orientation here is no longer a function of α as a single dominant variable, but of α plus a number of other variables.

As geotropic stimulation is increased, variability is decreased. The probable error expressed as a percentage of the mean θ decreases rectilinearly as log sin α increases. A better test of the notion that θ and the probable error expressed as a percentage of the mean θ follow the same law is to plot one against the other (Figure 3); the two are clearly proportional. At the high inclinations the gravitational component is prepotent in determining orientation. At $\alpha = 65$ degrees practically all trails were perpendicular to the base of the plane.

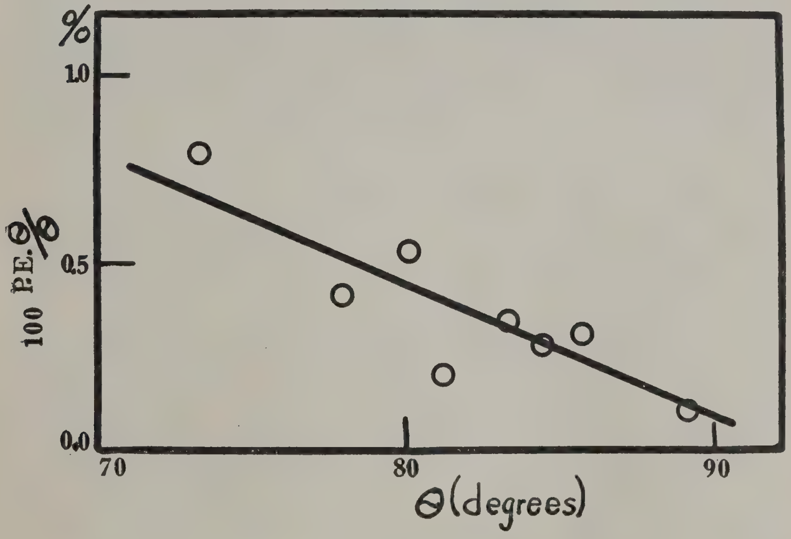

FIGURE 3

The *P.E.* expressed as a percentage of the mean θ decreases as θ the angle of orientation increases. The inverse correlation between θ and the variability of θ shows clearly that the same mechanism is responsible for both.

Summary

Young kittens placed horizontally on an inclined plane orient upward at an angle θ, which is definitely a function of the slope of the plane α. When α is 37 degrees or above θ can be expressed as a function of log sin α. Cosin θ plotted against sin α shows a straight line relationship. The geonegative range for these kittens was found to lie between 37 and 65 degrees, a usable range smaller than that found with other young mammals. As in the case of other forms the probable error of θ, expressed as a percentage of the mean θ, decreases rectilinearly as log sin α increases. This law expressing the variability affords an internal check on the data obtained.

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RELATIVISM AND THE SCHOOL-INDIVIDUALIST CONTROVERSY

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I

Definite trends in epistemology away from the classical correspondence theory of truth to the coherence theory as advocated by Bradley and Bosanquet have left a distinct impression on the entire body of scientific thought. This latter theory is an outgrowth of the general relativistic movement and carries with it in its basic assumptions the stamp of the movement. Truth, according to the coherence theory, is in no way a matching-up with an absolute "real" world which exists objectively, but consists, rather, in the development of an internal consistency in the whole theoretical structure. So argues the coherence theorist, the uncritical use of whose doctrines seems largely responsible for certain inadequately founded convictions among contemporary psychologists.

Although the authority of the coherence theory has not always been explicitly acknowledged, the direct as well as the indirect influence of the theory has furnished a new impetus to system making, an activity which has been particularly noticeable in the field of psychology. Accepting without reservation the coherence theory, the psychological systematist who is intent upon the establishment of a particular school has laid down as an axiom of scientific truth that in order for a system to be valid it must be strictly consistent with regard to the terms of its initial assumptions. According to the exponents of systems of psychology, attacks upon the validity of such scientific systems must, to be relevant, always be in terms of the systems' own assumptions, and refutation comes only when the systems are shown to be self-contradictory.

The authors have no quarrel with those who choose to accept this theory of scientific truth, but they do believe that much needless misunderstanding has been created by the unhesitant acceptance of this doctrine, with the result that certain inherent difficulties within the general theory have been lost sight of.

From the epistemological standpoint relativism starts with the primary assumption that, so far as the knowledge of man is concerned, the absolute universe, if it exists at all, can never be known. What we do know is always a partial knowledge, therefore, and, although the body of knowledge is constantly increasing with the accretion of new facts and theories, the absolute, i.e., the perfectly consistent system, can never be formulated. Consequently, even consistency is a relative thing. Difficulty in scientific thinking arises when the school-scientist loses sight of the element of relativity in the principle of consistency and accepts consistency as an absolute principle. He begins to regard his system as something absolute and tries to force within the limited confines of a static system the entire body of an ever-expanding science. This shows a flagrant disregard for the primary principle of relativity, namely, that *the experience of reality in general, and scientific truth in particular, are ever-expanding realms.*

Although, as we have suggested at the outset, this general idea of a relative coherence grew up as a part of the relativistic movement in scientific thought, the advocates of this doctrine have been losing sight of the original relativistic principles and have been giving it an absolutistic cast. Thus has arisen a controversy[1] between the school-makers and the individualists,[2] which comes about, as we shall show in this paper, because of two relatively divergent tendencies which are represented by the school-man and the individualist. Briefly put, the school-scientist is looking for consistency and stability, while the individualist is looking for a constantly changing scientific system which will accommodate the ever-increasing body of scientific fact. We shall try to show how each of these two tendencies is necessary to the healthy growth of a science and how it is that in the larger view of relativistic science these two tendencies can within limits be reconciled.

II

In contrasting the school-scientist with the individualist we shall endeavor to envisage the subject as a whole and not confine ourselves exclusively to any one viewpoint or any one school. Our efforts will be in the direction of noting general tendencies rather than specific cases. The typical school-psychologist will be contrasted with the typical individualist as regards outstanding qualities, although we admit quite frankly that certain school-men do not possess all the qualities we indicate, just as certain individualists do not embody some of the traits of the individualist. Probably no one individual would fit our picture of either type, but nevertheless we believe that our general picture of the school-man versus the individualist possesses validity.

Individualists, to be sure, started every school because it would take the individualistic personality to break away from traditional methods. In every case, however, when the originator of a system of psychology is successful in developing a school we believe that history shows that such an individual develops into the school-man type. For example, Wundt and Titchener were originators to some extent and no doubt regarded themselves as holding their systematic viewpoints very flexibly. Wundt changed his views on feeling considerably and Titchener altered his views about sensation quite materially during his lifetime. Nevertheless, from the viewpoint of the onlooker they were school-men, and they did seem to develop a more strict consistency as their respective reputations and schools developed.

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[1] It is worth while to note the disadvantage to which the individualist is put in any sort of a controversy. Individualists need almost a platform occasionally to maintain their own individualistic integrity against the attack of the school-men who take advantage of their inability to present a front. But individualists are not able to unite themselves in any very effective way, as a union, in effect the formation of an "individualists' school," would be a denial of the very principles they insist upon.

[2] See Boring (2), Klein (5), Wheeler (9), and Woodworth (11).

One of the main advantages of our delineation of the strict school-systematist and of the individualist lies in the view it gives us of the strengths and weaknesses of the two types. In certain respects the school-men are advancing the truth and in certain ways they are hindering its growth. The same thing holds for the individualists. As active participants we can certainly profit by a proper appreciation of the strengths and weaknesses of both.

III

It may be worth our while to consider a few of the general attitudes and methods in which the school-psychologist and the individualistic psychologist are likely to differ. Let us first turn our attention to the factors of cooperativeness, emphasis upon facts versus theories, and general tolerance.

In a concerted cooperative movement such as is found among the school-scientists we notice a tendency to forget differences in an effort to advance a common cause. This merging of like-minded individuals has its favorable as well as its unfavorable aspects. On the one hand, it tends to promote a cumulative growth, and to develop every systematic idea to its utmost.[3] On the other hand, in forgetting differences the school-man tends to become blind to opposing facts, to the lack of facts, and to the general vagueness of his interpretations.

Individualists, of course, progress spasmodically and contribute to the larger scientific system, which they cannot envisage on account of its vastness. Individualists seem to be comparable to discoverers; school-men to inventors. The discoverer hits upon something new without having much of an idea of what he expects, whereas the inventor works painstakingly to create something which he has already outlined. The school-systematist has a pattern which restricts his thinking in order to advance his system; the individualist is a more spontaneous creator. The school-man is apt to be like the conformist who works for the good of his group. The individualist is the nonconformist who works alone, either tolerant toward or skeptical of the prevailing schools.[4]

An important difference between these two viewpoints is found in the relative significance each ascribes to the factors involved in the problem of fact versus theory, the individualist tending to emphasize the empirical aspect and the school-systematist following the rationalistic tradition more closely. In general, the latter is better versed in theories, and the former is better acquainted with the facts. The individualist is apt to get lost in his facts and to be blind to the wider implications of his discoveries, just as the school-man is inclined to glorify out of all proportion to their actual significance the importance of his inventions. The truth, of course, lies somewhere between these two extremes, for facts and theories are interdependent and go hand in hand. It is as impossible to do anything with facts without a theory as it is to develop an acceptable theory without facts. Millions of men before the time of Newton had observed the fact of the falling apple, but, until science had advanced far enough to furnish a factual background to a theoretically-minded man like Newton, the scientific principle of gravitation remained undiscovered. On the other hand, it is an accepted rule of scientific method that the rationalistic superstructure must be bolstered up and confirmed by empirical evidence. Modern science had its inception[5] when Aristarchus insisted upon empirical verification by experiment as the basis and final test of scientific validity. Psychology cannot hope to prosper unless it preserves a balance between fact and experiment and realizes that the one cannot validly be divorced from the other.

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[3] As witness the experimental vigor of *Gestalt* psychologists since the inception of their movement.

[4] As examples of individualists exhibiting the broad tolerant attitude we can mention the following: F. C. Bartlett, E. G. Boring, R. Dodge, W. James, David Katz, K. S. Lashley, A. Michotte, E. Rubin, and R. S. Woodworth.

A trait common to the school-man is an intolerance or blindness toward ideas which oppose or fail to fit in with his system. Valuing only the similarities to his own system, the school-man finds them wherever possible and when he misses them he looks for errors in the works of others and thereby underestimates their contributions.[6]

He is especially disposed to set up straw men in order to put across his point, and he sometimes points out contradictions in a predecessor who was perfectly logical in terms of the facts at his disposal. The individualist is inclined to be more appreciative and humble in his perspective of psychology as a whole. The school-man, though more or less critical of his predecessors and contemporaries, is often utterly lacking in appreciation.[7]

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[5] See Boring (1, pp. 10 ff.).

[6] The following quotation from R. S. Woodworth's "Dynamic Psychology," in *Psychologies of 1930* (10, p. 327), with the possible exception of the third premise, represents a typical individualist's viewpoint upon these matters: "Any system of psychology which starts with the assumption that most students of the subject are on the wrong track has little chance of being adequate, however stimulating it may be for the moment. One might better start with such premises as these:

1) The presumption is that all sincere and able investigators are doing something worthy of being included in the system.

2) This presumption holds rather of the actual research of psychologists than of their attempts to formulate systems. In the latter effort, they are exposed to the danger of spinning out theories that have only a tenuous connection with their actual findings, and to the further danger of seeking to exalt themselves by the familiar process of trampling on the prostrate forms of their fellows.

3) The total psychological group is presumably wiser than its individual members, when the question is one of aim and trend."

IV

The main argument between the school-thinker and the individualist comes to a focus in the problem of consistency. Uncritically accepting the principle of internal consistency as the criterion of scientific validity, the school-thinker is altogether too prone to forget the fallibility of his doctrines, and in his enthusiasm for his hypotheses to go further than a more critical understanding of their limitations would warrant. It is true that the school-thinker is generally more consistent within his sphere than the individualist. The system the school-psychologist holds tends to promote the development of a simple and harmonious view of his facts, a very necessary aim of all science. Unquestionably, some assumption or hypothesis is often desirable as a starting point for scientific work. The source of trouble lies in the probability of the theorist's thinking becoming more vague, inaccurate, and static in proportion to its independence of experimentation. The faith of the school-scientist in unity and consistency is a valuable one in research, but the very uncritical enthusiasm that can promote truth in the beginning often in the end leads to vagueness and dogmatism. The individualist, on the other hand, may comprehend more impartially and accurately what he does discover. Because he has not contributed to building up a systematic program he is inclined to be more openminded and willing to admit a lack of harmony, and what is perhaps of equal importance *actually to search for discrepancies between his theory and his results.* To tear down systematic theoretical structures with crucial experiments and to erect new and more inclusive structures are two of the valuable contributions of individualists.

The typical individualist is often haphazard and inconsistent in his methodology and in his organization of conclusion from a systematic standpoint. Facts may be explained by the individualistic physicist on Monday, Wednesday, and Friday by the wave mechanics theory, and on Tuesday, Thursday, and Saturday by the corpuscular theory, and on Sunday by the principle of uncertainty. In the same way, the individualistic psychologist may be a behaviorist in one experiment, a structuralist in another, and a configurationist in a third. Explanatory principles are for the individualist not mutually exclusive. He may aim for consistency in his thinking about the particular investigation that he is at present working on. Whether he fits in to a certain school is determined principally by the stage of his research.[8] Basically, he regards his facts as more nearly absolute and permanent and his theories as more relative and temporary.

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[7] Note the general spirit of disparagement of earlier work and workers in books like Watson's *Psychology from the Standpoint of a Behaviorist* (8), and Köhler's *Gestalt Psychology* (6).

The school-psychologist's system is much like a building. Once it is up he wants to make the best use he can of it. He adds to it, alters it here and there, but, because of his sentimental attachment to it, he resists any suggestion on the part of his individualist friends to tear it down and build a more modern structure. When the school-psychologist passes away the building either disintegrates or is remodeled by someone else who gives it a different architecture, and probably a different name. The architectural consistency of the whole systematic structure will stand certain alterations but beyond a certain point the structure of the psychological movement loses its previous identity and must be abandoned or rebuilt from the ground up.

The school-man is aided by his systematic position as long as his system promotes experimentation. If his system is ahead of its time it may facilitate the development of his thinking for a longer period. But as no system contains the ultimate truth in all of its ramifications, any system is but a temporary affair which lasts for a limited time.[9] During the lean years of scientific discovery the school-man profits greatly because no major change is demanded in the framework of his system, and the entire structure, which is relatively consistent within itself, stands unchallenged. But during plentiful years of discovery systems change rapidly and a psychologist profits little from membership in a school.

During the early years of his school the systematist is so busy looking for easy facts to illustrate his theories that he is oblivious to vaguenesses, inconsistencies, and unexplained facts. Later, as experimentalists point out weaknesses, the school-man may admit obvious deficiencies but assert that the new theory works better than the old in spite of its defects. Finally, as the years wear on and the early hopes for complete substantiation do not materialize, or else new facts arise which the theory cannot conveniently account for, psychologists as a whole discard the "system" and keep only the few workable remnants.[10]

In spite of this inevitable dissolution of a system, the systematic theorist always resists this merging of his system into a larger system because he feels his system is a part of him. He will permit a certain amount of change, that is, such change as he believes he can legitimately concede in accordance with his strict conception of consistency. For this reason past systems have shown a limited degree of usefulness. They have performed a certain function for a while, and then they have died or else have been reborn in broader and more flexible conceptions that could account for both new and old facts.

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[8] See Lashley (7, Chap. XI) for an illustration of this sort of thing.

[9] Consider the systems of psychology that have existed as schools, made their contributions, and merged into the larger body of psychological knowledge: associationism, structuralism, imageless-thought, act psychology, *Gestalt-qualität,* functional psychology, purposive psychology, behavioristic psychology.

[10] For example, structuralism has worked out for us a careful technique for introspection and a most useful set of facts relating to the special senses. Behaviorism has promoted the technique and has furnished us with a valuable collection of data on animals and children. The imageless-thought group and the associationists have contributed to our knowledge of higher thought processes. *Gestalt* psychology has improved our techniques and added to our facts in the fields of perception and learning.

Just as the systematist or school-thinker places his emphasis upon observed consistency, the individualist emphasizes the divergent aspect of scientific truth—he takes account of this growth even though sometimes at the expense of apparent consistency. As we have seen, it is just this factor of constant change that makes consistency a relative thing, and by no means a thing to be striven for above all else, as the school-thinker is apt to regard it.[11] The idea of having a system in which the limits are defined is repugnant to the individualist because of its absolutistic implications. The systematist's relatively static attitude and his tendency to resist change are viewed by the individualist with distrust, because he sees that in all mental life, even in the case of such relatively stable things as the concepts that go to make up our initial fundamental assumptions, there is change and constant expansion. He cannot lead himself to believe that the whole of the universe can be grasped intelligibly. His discoveries make him realize that there is always something just beyond his conscious understanding that is worth knowing. He distrusts a world-view because it may blind him to vaguenesses and details which are not accounted for. As a scientist he wants to be clear; he wants to test his temporary assumptions by crucial experiments under carefully controlled conditions. He wants his knowledge to be more precise and more complete.

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[11] It is, of course quite possible for the school-scientist to maintain a broad and relativistic attitude toward scientific truth, if, as we have indicated above, he keeps in mind the limitations of his system. But when he dogmatically proceeds to apply his own limited criterion of truth to conceptions that were never advanced under his viewpoint, he is committing a grave error. For example, it would be manifestly unfair to criticize James in terms of the coherence theory alone, because at the outset of his *Principles of Psychology* he is very careful to eschew any consideration of his work as strictly consistent, saying: "The reader will in vain seek for any closed system in the book. It is mainly a mass of descriptive details, running out into queries which only a metaphysics fully alive to the weight of her task can hope successfully to deal with. That will perhaps be centuries hence; and meanwhile the best mark of health that a science can show is this unfinished-seeming front."

The pragmatic epistemology of James obviously emphasizes other considerations than that of strict consistency. James may not have been as consistent as certain school-psychologists of his time, but he did have a marvellously inclusive grasp of the subject that uncompromisingly consistent school-men might well attempt to develop.

V

A recognized fact in science is the continual unfolding of scientific truth. Conceptions that were at one time adequate to account for the known facts are made obsolete through the accumulation of new facts and new theories, and must be thrown aside in favor of more serviceable viewpoints. There is thus a parallel or integrative increase of fact and theory as the whole body of scientific knowledge expands. From the theoretical standpoint this increase comes about largely through the reconciliation of apparently contradictory ideas in a separate theoretical consideration. When a theory is advanced it is frequently the negative criticism levied against it quite as much as or more than the positive credence attached to it that results in its clarification and utilization. Sometimes the facts that refuse to be adequately accounted for by a given conception are of such importance that they demand another theoretical explanation. This can be seen in the case of opposing interpretations by two different systems.[12] Here it is obviously better not to bind oneself strictly to either viewpoint. The only chance for a consistent body of truth to emerge from such divergencies lies in the individual's freedom to adopt a newer and broader synthesis in which these *quondam* contradictions may find reconciliation.[13]

Whether one chooses to belong to a particular school or to maintain his individuality,[14] a relativistic consideration of science demands, as has been indicated at the outset, that one take cognizance of the continual expansion of the general body of scientific truth and that one make every effort to provide a place for the new facts and theories constantly arising. As has been shown, there is a definite tendency on the part of the school-psychologist, in his ardor for consistency to neglect this point. At the same time it is equally the task of the relativistic scientist to organize his science so as to provide for a measure of consistency. *It is a matter, then, of striking a balance between the principle of consistency on the one hand and the factor of inclusiveness on the other, rather than of placing the emphasis on either to the exclusion of the other.* The fact that psychology has not yet recognized the importance of both these factors indicates it is not yet out of its adolescence.[15] When the science reaches full maturity systematists will no doubt think more impersonally and individualists will think more systematically.

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[12] For example, although numerous facts of learning relating to the influence of material, whole versus part learning, spacing in practice periods, periodicities in progress, incentives, et cetera, must be admitted as valid by *Gestalt* psychologists, they have developed a new theory of learning based principally on the negation of the importance of the older laws of frequency and effect. The *Gestalt* psychologists' chief positive contribution—insight—has, to be sure, proved very stimulating, but before it can be incorporated into the general body of psychological knowledge it must be worked out in laborious detail in individual experiments.

[13] An outstanding example of this is found in the field of physics, in which we find the wave theory of light and the quantum theory of light apparently contradictory to each other. For instance, P. R. Heyl (4, p. 189) says: "The trend of modern physical thought is toward a blending of the two ideas, wave and quantum, though to what end is not yet evident. It is recognized that both the quantum and the wave theories have a valid reason for existence, that each supplements the weak points of the other. As Lodge says, the two concepts are like a shark and a tiger, each supreme in its own element and helpless in that of the other. The final form of our concept of the nature of radiant energy will probably be one of a broad and general character of which both the quantum theory and the wave theory will be seen to be special cases."

[14] See Boring (3), for a presentation of the broad individualistic systematist's viewpoint.

VI

We may, in conclusion, present as a concise statement of the relativistic attitude toward the school-individualist controversy that a consistent application of the principle of relativity to scientific theorizing requires that systematic thinking be flexible enough to permit viewpoints to be adjusted to this ever-expanding total body of truth with a measure of consistency. If these two basic principles—*consistency* and *inclusiveness,* the two poles between which the scientific structure must be set up—are kept clearly in mind and a judicious balance between the two is maintained, the distinction between the school-psychologist and the individualist is somewhat superfluous. The two divergent tendencies find reconciliation in terms of a broader and more balanced relativistically-consistent perspective.

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[15] "There is a curious contrast in present-day psychology between the mutual hostility of the several schools, on the one hand, and the solidarity of the group of psychologists, on the other. From the insistence of each school on the futile and reprehensible tendencies of the others, you would scarcely expect to find them meeting in associations and congresses on a footing of mutual respect and interest, nor to see them laboring together on abstract journals and the like; yet this cooperation is just what you do find. They must have more in common than would at first appear, and this curious cleavage into schools, a phenomenon almost peculiar to psychology among the sciences of the day and probably to be regarded as a symptom of adolescence, must be less fundamental than it seems"—R. S. Woodworth (10, p. 327).

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THE EFFECT OF LUMINOSITY ON THE APPREHENSION OF ACHROMATIC STIMULI

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In an earlier experiment by Tinker (1), luminosity of colors appeared to be much more potent than hue as a determinant of the span of visual apprehension for colored letters both in homogeneous and in heterogeneous color series. The present study was planned to investigate the effect of luminosity or brightness on visual apprehension of achromatic letters.

Construction of stimulus material and experimental procedure were similar to these in the earlier experiment. Black, dark gray, and light gray letters (consonants), 3 by 4½ inches, were cut from Milton Bradley papers, and pasted onto white cardboards, nine letters per series. The experiment involved apprehension of 12 homogeneous (4 of each brightness) and 12 heterogeneous brightness series. In the homogeneous series, all letters on a stimulus card were of the same brightness; and in the heterogeneous series, each succeeding letter on any stimulus card was of a different brightness. The sequence of brightness was systematically arranged.

A total of 128 university sophomores served as subjects. They were tested in groups of about 30 each. The stimulus cards were exposed, one at a time, for a period of three seconds. Exposure was achieved by uncovering and covering the stimulus card in a position from which the letters were clearly visible in all parts of the classroom. A stop-clock was used for timing. The subjects were instructed to view the letter series attentively while it was exposed, and, as soon as the card was covered, to write down as many of the letters as they could remember and in the same order as on the exposure card.

The responses were scored for the number of letters correctly reproduced. The reliability of the test as a measure of visual apprehension is high whether misplaced letters are given half (Scoring Method I) or full (Scoring Method II) credit. The odd-even correlation and the reliability coefficients for the whole test, obtained by applying the Brown-Spearman "prophecy" formula, are shown below for both methods of scoring:

Scoring Method I: $r = .843$, $r_x = .915$

Scoring Method II: $r = .827$, $r_x = .905$

The total number of times that letters were correctly reproduced in each degree of brightness, irrespective of whether they were misplaced or in proper sequence, was computed. Each degree of brightness appeared 36 times in both the homogeneous and heterogeneous series. The average scores for the group of 128 subjects appear in Table 1.

In the homogeneous series, black and dark gray letters have practically identical means, but the apprehension score for light gray is definitely smaller. The trend is more marked in the heterogeneous series. The apprehension score for black is largest, for dark gray next largest, and for light gray smallest. The sizes of the differences, the intercorrelation between scores and the reliability of the direction of the differences are given below. (The formula for correlated measures was used to compute the standard error of the difference.)

TABLE 1

THE INFLUENCE OF BRIGHTNESS ON THE APPREHENSION OF LETTERS

$N = 128$ university sophomores

Stimulus	Homogeneous Mean	σ_M	Heterogeneous Mean	σ_M
Black	24.63	.34	25.24	.34
Dark gray	24.70	.31	24.50	.31
Light gray	23.29	.30	21.06	.24

HOMOGENEOUS SERIES

Black *vs.* dark gray: $D = .07$, $r = .741$, $\dfrac{D}{\sigma_D} = .115$

Black *vs.* light gray: $D = 1.34$, $r = .447$, $\dfrac{D}{\sigma_D} = 2.45$

Dark gray *vs.* light gray: $D = 1.41$, $r = .445$, $\dfrac{D}{\sigma_D} = 2.72$

HETEROGENEOUS SERIES

Black *vs.* dark gray: $D = .74$, $r = .775$, $\frac{D}{\sigma_D} = 1.20$

Black *vs.* light gray: $D = 4.18$, $r = .182$, $\frac{D}{\sigma_D} = 9.24$

Dark gray *vs.* light gray: $D = 3.44$, $r = .082$, $\frac{D}{\sigma_D} = 8.46$

These results indicate that the direction of the differences between light gray and either black or dark gray is fairly stable.

The greatest luminosity contrast between stimuli and white background occurred with black, the next greatest with dark gray, and the least with light gray letters. The brightness of the dark gray was only slightly different from that of the black (about 16 per cent). In the heterogeneous series, and to a lesser degree in the homogeneous series, the results show that there is a direct relation between apprehension scores and luminosity difference between letters and background.

SUMMARY AND CONCLUSIONS

1. Apprehension scores for black, dark gray, and light gray letters were obtained in both homogeneous and heterogeneous brightness series from 128 subjects.
2. In the homogeneous series the apprehension score for light gray was definitely smaller than for black and dark gray which were practically equal.
3. In the heterogeneous series the largest apprehension score was for black, the next largest for dark gray, and the smallest for light gray letters.
4. The results justify the conclusion that the amount of luminosity contrast between stimulus and background is an important determinant of visual apprehension.

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THE EFFECT OF VARIATIONS IN COLOR OF PRINT AND BACKGROUND ON LEGIBILITY

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The increased use of color in special kinds of printing emphasizes the importance of scientific knowledge concerning the effect of various color combinations of print and paper on legibility. Colored print may be very readable on one color of paper but difficult to read on others. The purpose of this experiment is to investigate the effect of variations in color of print and paper on perceptibility of isolated words, by determining the farthest distance from the eyes at which five-letter words can be read accurately.

The stimulus material consisted of 64 easy five-letter words printed in 10-point, Scotch Roman, lower case type with Ruxton's colored ink on Rainbow coverstock. The various combinations of ink and paper are listed below. The trade name of the color combination is given first and the observed effect of the combination follows the trade name in parenthesis:

Trade name	*Observed effect*
Black jobbing on white	(Black on light grayish white)
Grass green on white	(Dark green on light grayish white)
Lustre blue on white	(Dark blue on light grayish white)
Black jobbing on yellow	(Black on yellow with slight orange tinge)
Tulip red on yellow	(Light red on yellow with slight orange tinge)
Tulip red on white	(Light red on light grayish white)
Grass green on red	(Dark grayish green on red)
Chromium orange on black	(Dark lemon yellow on dark grayish black)
Chromium orange on white	(Light orange on light grayish white)
Tulip red on green	(Dark brown on dark green)
Black jobbing on purple	(Black on dark purple)

The variation of the observed effect in certain instances from what might be inferred from the trade name indicates the need of knowing both.

For each of the 11 color combinations, 16 of the stimulus words were mounted on each of four sheets of 8½ x 11 inch cover-stock of the same color as the paper on which the words were printed. The words were arranged in random order, four lines of four words each per sheet. Each subject read the black on white and one other color combination. The black on white served as a standard in each comparison. In presenting the stimulus cards to the subject, the black on white and each color combination were systematically varied to control practice and fatigue effects.

The apparatus for determining legibility by the distance method consisted of an extended bench, along which moved a sliding carriage with the words to be read. At one end of the bench was a head-rest. The reading material was uniformly illuminated with an intensity of 34 foot-candles per square foot.

A sheet of 16 words was placed in the carriage at the farther end of the bench and the readings begun. The stimulus material was moved successively nearer the subject by 20-centimeter steps until every word was read correctly. This apparatus and method are fully described by Tinker (1).

In all, 66 university students served as subjects. There were 6 subjects for each comparison of a color combination with black on white print.

The direction of the differences between individual average scores (mean of black on white *vs.* mean of color combination) showed a high degree of consistency from subject to subject. The directions of these differences are listed below. Minus indicates that the average score for black on white was smaller than that of the color combination with which it was compared.

Blue on white: all minus differences
Black on yellow: all minus differences
Green on white: 4 minus, 2 plus differences
Green on red: 1 minus, 5 plus differences
Red on yellow: 1 minus, 5 plus differences
Red on white: all plus differences
Orange on black: all plus differences
Black on purple: all plus differences
Orange on white: all plus differences
Red on green: all plus differences
Red on white: all plus differences

The mean score for each color combination and for black on white are given in Table 1. Each mean is an average of 384 reading scores.

TABLE 1

THE EFFECT OF VARIATIONS IN COLOR COMBINATIONS ON THE LEGIBILITY OF PRINT

The mean score is the average distance in centimeters from the eye at which the words were read.

		Color combination		Black on white			
Color of ink and paper	Legibility rank	Mean	σ_M	Mean	σ_M	Diff.	$\frac{Diff.}{\sigma_{diff.}}$
Blue on white	1	162.4	.22	150.6	.20	—11.8	3.97
Black on yellow	2	166.5	.27	155.7	.25	—10.8	2.96
Green on white	3	182.5	.24	177.1	.22	— 5.4	1.66
Black on white	4	166.6*	.22	166.6*	.22	0.0	0.00
Green on red	5	164.0	.20	169.7	.22	+ 5.7	0.57
Red on yellow	6	140.6	.19	150.2	.18	+ 9.6	3.66
Red on white	7	161.1	.24	179.9	.25	+18.8	5.42
Orange on black	8	152.7	.19	172.7	.19	+20.0	7.49
Black on purple	9	99.7	.14	161.1	.22	+61.4	23.52
Orange on white	10	91.8	.12	178.2	.18	+86.4	40.00
Red on green	11	78.3	.14	170.4	.23	+92.1	34.36

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*This mean for black on white is an average of means for the ten subgroups.

In the last two columns of the table are listed the differences between these means and the ratio of each difference to its standard error. A minus sign before a difference indicates that the average score for black on white was smaller than for the color combination.

In the table, the color combinations are listed in order of legibility. Blue print on white paper was found most legible, and red on green least legible. The last column of the table shows that, with the exception of green on white and green on red, the directions of all differences are very stable. The legibility of black on white, green on red, and green on white are, therefore, all approximately equal. The printing combinations show a steady decrease from most to least legible.

Comparison of the observed effects (listed above) of the color combinations shows that those combinations that rank high in legibility are the ones which have marked brightness contrast between print and background. Those of poor legibility have comparatively little brightness contrast between print and paper. Blue on white, black on yellow, green on white, and black on white provide good legibility; green on red, red on yellow, and red on white provide fair legibility; and orange on black, black on purple, orange on white, and red on green provide poor legibility. Those providing poor legibility should never be used in any printing where legibility of copy is a practical consideration.

Employing the same color combinations, Tinker and Paterson (2) determined the influence of variation in color combinations on speed of reading. Their order of legibility correlates +.864 with the order in the present experiment and 4 in this study.

Employing the same color combinations, Tinker and Paterson (2) determinded the influence of variation in color combinations on speed of reading.

Summary and Conclusions

1. The comparative legibility of 10 color combinations in addition to black on white was determined by measuring the farthest distance from the eyes at which single words could be recognized. Ten groups of 6 university students each served as subjects. In each group the subjects read 64 words in black on white and also in the color combination with which it was compared as a standard.

2. Striking differences in legibility were discovered. In general, the greater the luminosity or brightness differences between symbol and background, the greater the legibility of the print.

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THE FACTOR OF SPEED

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Several recent studies have shown that, although it is true that power (level of achievement) and rate are highly and positively correlated, there is always present a small but genuine group of individuals who are handicapped by the imposition of time limits (1). That is, they are the exceptions in whom rate and power are not positively related to a very marked degree. It was suggested, therefore, that every mental test should be studied with a view to determining how far each might be making demands on speed.

The present investigation is concerned with the Ohio State University Psychological Test. About October 1, 1930, it was administered to students entering Cornell, with the usual time limits. Several months later (in December) the test was again given to a sampling of 117 students from the original group. The second time, the test was administered without time limits in order to study the factor of speed as an influence upon the scores of this psychological test. Table 1 shows the distribution of scores of the

TABLE 1

Frequency Distributions of Ohio State University Psychological Test Scores

Class interval	Scores with regular time	Scores with No time limit
40-49	1	
50-59	0	
60-69	0	
70-79	6	
80-89	3	
90-99	7	
100-109	11	
110-119	11	
120-129	20	
130-139	11	
140-149	12	1
150-159	10	3
160-169	9	3
170-179	6	6
180-189	2	4
190-199	2	8
200-209	3	5
210-219	1	15
220-229	2	19
230-239		17
240-249		11
250-259		13
260-269		11
270-279		1

117 students who were used in the experiment. It will be noted from the regular-time scores that the experimental group shows a satisfactory distribution. It will also be observed that the no-time-limit scores are distinctly skewed. These data will, however, be analyzed further at a later point.

The following table (Table 2) presents a summary of the statistical tabulations of the data. For the scores in regular time, the measures of central tendency and variability are of the sample (117 subjects), not of the whole group from which the sample was taken. The decile ranks assigned to these scores, however, are with respect to the whole group. The scores given for each decile are, of course, the lower limits.

TABLE 2

MEASURES OF REGULAR-TIME AND NO-TIME-LIMIT SCORES

		Regular-time scores	No-time-limit scores
Mean		134.06±3.16 (Standard error)	223.72±2.72 (Standard error)
Median		134.75	227.11
Standard deviation		34.22	29.48
Coefficient of variation		25.52	13.18
Decile	I	178	260
	II	160	251
	III	150	241
	IV	140	234
	V	131	227
	VI	125	221
	VII	116	213
	VIII	106	198
	IX	90	178
	X	49	140
	Range	49 — 227 = 178	142 — 272 = 130

Besides the obvious increases in the scores, as noted in the frequency distribution, certain distinct trends are apparent in Table 2. The no-time-limit score distribution is skewed, this fact being indicated, among other things, by the distance between the mean and the median. The standard deviation of the no-time-limit scores is actually smaller than that of the regular-time scores; and, furthermore, the coefficient of variation of the former is only about 50 per cent as large as that of the latter. Also, the range of the no-time-limit scores is distinctly smaller than that of the regular-time scores, namely, about 73 per cent. These facts—the coefficients of variation and the ranges—indicate, of course, greater homogeneity in test results when the time factor is eliminated. Viewed together, these statistical indices demonstrate, first, that the time limit influences the scores of all those taking the test, and, secondly, that some subjects are influenced more than others. It seems rather clear from the results that one factor being measured by the psychological test under consideration is rate of response, at least in part. This will be further shown by the coefficients of correlation.

That speed is an essential factor is also demonstrated by Table 3 which shows the average gains in the scores of the several original decile groups.

TABLE 3
AVERAGE GAINS IN THE SCORES OF THE SEVERAL ORIGINAL DECILE GROUPS

Decile	Mean gain
I	61.75
II	81.69
III	76.30
IV	92.00
V	86.29
VI	92.79
VII	90.50
VIII	99.17
IX	100.90
X	108.60

Although the statistical treatment thus far presented indicates the importance of the factor of speed, it does not show whether the relative positions of the subjects are changed to any great extent when the time limit is removed. This problem of change in rank can be investigated through the use of coefficients of correlation. In the earlier papers it was pointed out that the greater the part played by speed in a test, the smaller will be the coefficient of correlation between scores obtained under regular time limits and scores obtained under no time limit. It was stated that "if . . . . there is a low correlation, we may conclude that the test with its original time limit measures speed for the most part, inasmuch as it appears that the slow, plodding, accurate individual is able to score much higher if he is given sufficient time to undertake the solution of each problem, whereas the subjects whose principal quality is rapidity of response may profit little or none from the increase in time, for they will reach an impasse beyond which progress will not be possible even with the added opportunity of attempting the solutions of the increasingly difficult items" (1, pp. 85 ff.). Conversely, if the test calls chiefly upon power, the two sets of scores will show a very high, positive correlation. By the same reasoning, a coefficient of any magnitude, derived in this connection, may be interpreted for an evaluation of the factor of speed.

The product-moment correlation coefficient for the two sets of raw scores is +.72±.03. The correlation between the deciles of each set of scores is +.71±.03, showing no real difference between the raw score relationship and that of the deciles.

TABLE 4
CORRELATION OF REGULAR-TIME AND NO-TIME-LIMIT RAW SCORES

Scores: Regular Time

		40	50	60	70	80	90	100	110	120	130	140	150	160	170	180	190	200	210	220	Total
	270														1						1
	260									1		2	1		1	2	1	2		1	11
	250											1	1	5	2		1	1	1	1	13
	240								2	1	1	1	3	1	2						11
	230					1		1	1	5	1	5		3							17
	220	1					1	3	2	4	5	1	2								19
Scores: No-time-limit	210					1		1	2	5	2	2	2								15
	200						1		1	1	2										5
	190					1	2	2	1	1			1								8
	180						1	2		1											4
	170				2		2	1	1												6
	160				1			1	1												3
	150				2					1											3
	140				1																1
	Total	1	0	0	6	3	7	11	11	20	11	12	10	9	6	2	2	3	1	2	117

TABLE 5
CORRELATION OF DECILES OF REGULAR-TIME AND NO-TIME-LIMIT SCORES
Decile Rank: Regular Time

		X	IX	VIII	VII	VI	V	IV	III	II	I	Total
	I					1		2	1		8	12
	II							1	1	5	4	11
	III			2		1	1	1	3	4		12
Decile	IV	1			1	2	1	2		4		11
rank:	V	1	2	2	1	3	1	3	1			14
no	VI		1	1	3	1	4	1	1			12
time	VII			1	3	2	2	2	1			11
limit	VIII	2	3	2	2	2	2		1			14
	IX	1	2	4		1			1			9
	X	5	3		2	1						11
	Total	10	11	12	12	14	11	12	10	13	12	117

The double-entry tables (Tables 4 and 5) constructed in the calculation of the correlation coefficients are included here because they detail clearly the changes resulting from the two administrations of the test. Table 4 includes the arrays of the raw scores, and Table 5, those of the deciles.

The correlations of +.72 and +.71 shown above are not low. Nor are they "very high." They are what the writer would prefer to call "very marked." They are too far removed from unity to be explained away on the basis of chance variation. Naturally, this introduces the question of reliability. But in this connection the authors of the test state that the coefficient of reliability is "well over +.90." The difference between the coefficient of reliability and those derived by the writer is, of course, significant. The explanation must, therefore, be sought elsewhere than in low reliability; and the writer believes it is to be found in the fact that there is—as previously stated—a relatively small group of subjects who are slow workers, whose real levels of achievement, therefore, are not revealed under conditions involving time limits. They are the exceptions to the generalization that rate and power go hand in hand. It is not unlikely, also, that a still larger number of individuals are variously affected by time limits; for, of course, the correlation between rate and power is by no means perfect.

It is important to note, in addition, the following correlations:

Regular-time scores and time required when no time limit was imposed	—.39
No-time-limit scores and time required when no time limit was imposed	—.01

These indices again demonstrate that speed is a factor to be taken into account in the Ohio State University Psychological Test. For, in the first place, the coefficient of —.39 indicates that there is a tendency for those scoring highest under time limits to require less time for the completion of the test when no time limits are set. The coefficient of —.01 is altogether consistent with the view set forth in this paper, for it merely indicates that there is no relationship between the no-time-limit scores and the time consumed in achieving those scores. In other words, nearly all degrees of speed, or rate of work, will be found at nearly all levels of achievement when there are no time limits.[1]

From Tables 4 and 5 a clear idea may be had of the changes resulting from the administration of the test under the two sets of conditions: regular time and without time limits. The distribution of the changes in decile ranks caused by the elimination of the time limits permits selections of those cases in which speed or slowness is apparently a potent factor in the test score (Table 6).

TABLE 6

FREQUENCY DISTRIBUTION OF CHANGES IN DECILES FROM REGULAR-TIME TO NO-TIME-LIMIT SCORES

Changes Number of deciles	Frequency
—6	1
—5	1
—4	2
—3	8
—2	12
—1	25
0	31
+1	15
+2	8
+3	7
+4	2
+5	4
+6	1

Because the standard errors of the two obtained sets of scores are so small, it is probable that a change in rank of two deciles or more is significant for our problem and has some relation to the influence of the time factor. If this view is accepted, then it appears that the changes in 39.3 per cent of the cases are significant. It may then be said that in that percentage of cases the time factor has acted favorably or unfavorably when the psychological test was applied with regular time limits. Furthermore, in 22.2 per cent of the cases the shift in decile rank is of an extreme nature (three deciles or more).

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[1] The range of time required was from 77 to 193 minutes.

Further evidence of the importance of rate of work is to be found in the following times required when no time limits were set:

Mean time of entire group (117)	121.15 minutes
Standard deviation of time for entire group	23.5 minutes
Mean time of those who improved 2 deciles	140.45 minutes
Mean time of those who improved 3 or more deciles	143.3 minutes
Mean time of those who dropped 2 deciles	103. minutes
Mean time of those who dropped 3 or more deciles	113.3 minutes

From the foregoing data it appears that the Ohio State University Psychological Test does make demands upon speed; less so than other tests, perhaps, but more so than still others (1). These results confirm, furthermore, the view, previously expressed, that by many of our present measuring devices we are obscuring the real levels of attainment of a small, though important, number of individuals. This group presents a genuine problem in the interpretation of the score of any given individual; for, clearly enough, in evaluating an individual score, one must always bear in mind the existence of the subject handicapped by time limits, who is hindered in his attempts to achieve a score which shall correctly represent his level of ability. Now, all would grant that the person who is capable of performing rapidly tasks of a certain difficulty is "more able" than another who requires more time to do the same thing equally well. Yet, if we are seeking all dimensions of intelligence, we cannot afford to overlook the influence of rate of work upon apparent level, as indicated by current mental tests.

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A BASIS FOR CUTANEOUS LOCALIZATION

Hudson Hoagland

The distribution of sensitive areas supplied by cutaneous nerves in the frog, *Rana temporaria,* has been studied by Adrian, Cattell, and Hoagland (1) and by Hoagland (3), page 276 of the present number of this journal. Action potentials in response to touch and to acid on the skin were recorded in dorsal cutaneous nerves and the areas of distribution of the nerves were mapped by observing the regions from which nerve impulses could be elicited. It was found from the examination of many preparations that the dorsal cutaneous nerves supply patches of skin varying from 50 to 200 square millimeters in size and that there is considerable overlap of the areas (cf. figure on page 283 of this number of the journal). Nearly any point on the skin of the back initiates impulses in at least two spinal nerves and in many cases in three or four. Since branches from the dorsal root ganglia other than the dorsal cutaneous rami supply lateral and ventral parts of the skin, it is probable that dermal stimulation at any one point initiates different frequencies of impulses in several nerves, the patterns of frequencies being characteristic of the point stimulated.

Spots supplied by single fibers of the dorsal cutaneous nerves were also mapped (cf. figure on page 284 of this issue). Single fibers were found to supply regions of from 4 to 100 square millimeters in area. Since there are 50±5 fibers in the dorsal cutaneous nerves, there must be a great amount of overlap of the areas supplied by single fibres since, without overlapping, it would be impossible for an area of the size of that typically found to be supplied by a nerve trunk to contain 50 typical areas corresponding to single fibers.

The stimulation of a spot on the skin will presumably set up characteristic frequencies of impulses in specific fibers in several nerve trunks (cf. also Nafe, 4). Each point on the skin, regardless of the nature of the stimulus, will presumably initiate its peculiar pattern of frequencies in specific groups of fibers due to the extensive overlapping, and these patterns may be thought of as "local signs." Increasing the intensity of stimulation of an area will increase all of the frequencies in the various fibers from the area, but, in general, the relative frequencies in the fibers will remain substantially constant for a given point on the skin.

The classical local sign of Lotze was based in part on the notion of intensive excitatory patterns arising from local differences in the mechanical consistency of the skin and sub-cutaneous tissues. Since, according to the work of Adrian, frequency of nerve impulse may be regarded as the concomitant of sensory intensity, we may consider spots on the frog's skin as setting up characteristic intensity ratios in specific fibers. A basis for localization, therefore, appears to be accounted for as a corollary of the overlapping of areas supplied by nerve fibers.

It is known that the frog localizes with considerable precision. A piece of filter paper soaked in an irritant such as acetic acid and placed on the skin is promptly kicked off, usually with the foot nearest the spot. Experiments are now in progress in which it is hoped to measure precision of localization to a gradually anaesthetizing stimulus and correlate the measured localization with changes in frequency of response in the nerve fibers supplying the spot.

Adrian and Matthews (2) have shown that it is impossible to confine the electrical discharge to a single fiber in the optic nerve of the eel or the frog by reducing the size of the area illuminated. They report what is equivalent to a spread of excitation, the magnitude of the discharge, within limits, being proportional to the quantity of light received by the retina. From this fact, and from the anatomical arrangement of the nerve fibers with the retinal sensory elements and ganglion cells, it is probable that there may be considerable overlapping of areas supplied by fibers in the optic nerve. Such an overlapping might serve as a basis for retinal localization as in the case of the frog's skin. In the human fovea each cone may be connected to a single fiber of the optic nerve, and here the centrally projected pattern of intensities would approach the limit of simplicity. The close point-to-point correspondence between retina and occipital visual cortex in the higher vertebrates is consistent with this notion of retinal localization.

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3. Hoagland, H. Specific afferent impulses and cutaneous sensibility. *J. Gen. Psychol.,* 1932, **6**, 276-295.
4. Nafe, J. P. The sense of feeling. Chap. 9 in *The foundations of experimental psychology,* ed. by C. Murchison. Worcester, Mass.: Clark Univ. Press; London: Oxford Univ. Press, 1929. Pp. 392-413.

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ANNOUNCEMENT OF TRIPS TO GERMAN AND AUSTRIAN PSYCHOLOGICAL INSTITUTES AT THE CONCLUSION OF THE INTERNATIONAL CONGRESS OF PSYCHOLOGY IN COPENHAGEN, AUGUST 22-27, 1932

By agreement with the German and Austrian members of the Vorstand of the International Society of Psychology, the Vorstand of the German Gesellschaft für Psychologie will arrange for foreign members to visit the larger German and Austrian psychological institutes after the Congress. The organization of the round trips is in the hands of Professor D. Katz, University of Rostock. At the earliest possible date Professor Katz will get in contact with the proper persons to carry out the suggestions of members who are interested. Additional announcements concerning these trips will be made later. For further information write to Professor D. Katz, University of Rostock, Germany.

APPARATUS

UNIFORM CURRENT FOR CONTINUOUS, STANDARD UNIT RESISTANCE RECORDS[1]

CHESTER W. DARROW

The advantages of continuous quantitative records in standard units by the sensitive Wheatstone bridge method as originally described (1) are preserved in this modification of the *Behavior Research Resistance Box.* Additional advantages offered are that by this modification the current through the electrodes is necessarily and automatically kept uniform from subject to subject, that the bridge is automatically balanced, and that, if desired, one scale of standardization may be used for all subjects regardless of their respective resistance levels. Greater simplicity and economy of construction are also merits.

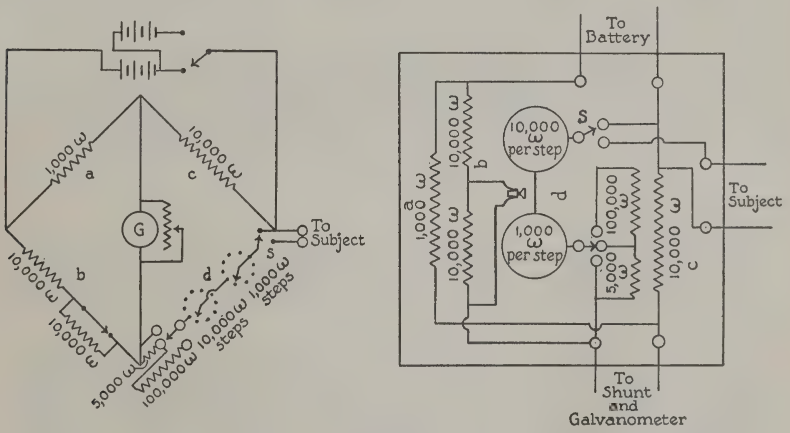
1,000 ω
a
c
10,000 ω
G
To Subject
S
b
10,000 ω
d
1,000 ω steps
10,000 ω steps
10,000 ω
5,000 ω
100,000 ω
To Battery
S
10,000 ω per step
10,000 ω
b
a
1,000 ω
d
10,000 ω
1,000 ω per step
100,000 ω
5,000 ω
10,000 ω
c
To Subject
To Shunt and Galvanometer

FIGURE 1

The bridge is constructed as indicated in Figure 1. A fixed 1 to 10 ratio is maintained in arms *a* and *b* by resistance of 1,000 ω and 10,000 ω respectively. With a fixed 10,000 ω resistance at *c* the bridge is automatically balanced when 100,000 ω is introduced into the *X* arm at *d.* For this 100,000 ω a standardized variable high resistance having two dials, 10 x 10,000 ω and 10 x 1,000 ω, respectively, plus a 5,000 ω fixed resistance are recommended. Setting the high resistance dial at 90,000 ω and the lower value dial at 5,000 ω with the additional 5,000 ω in series brings the bridge to balance. Adding or subtracting 1,000 ω units on the smaller unit dial gives a scale of plus and minus 1,000 ω galvanometer deflections either way from the 100,000 ω balance. As long as the sensitivity of the galvanometer remains unchanged, the same scale applies to all subjects. The switch, s, provides for the introduction of the subject into arm d of the bridge, and a shunt provides protection of the galvanometer during this introduction and during the consequent compensation to return the circuit near enough to balance for the galvanometer to be within the recording range.

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[1] Studies from the Behavior Research Fund, Chicago. Series B, No. 176.

The high resistances employed in this circuit necessitate the use of a relatively high external potential, but with 4.5 volts (3 dry cells) applied to this circuit, the following formula applies for the entire current through the bridge:

$$\frac{E}{I} = R$$

$$\frac{4.5}{\mathrm{I}} = \frac{1}{\dfrac{1}{1,000} + \dfrac{1}{10,000}} + \frac{1}{\dfrac{1}{10,000} + \dfrac{1}{100,000}}$$

$$\mathrm{I} = 0.000,45 \text{ amperes}$$

And since only one-eleventh of this current passes through arm d at balance, only 0.0409 milliamperes passes through the subject. There is an addition or a subtraction of less than one thousandth of a milliampere for each 1,000 ω change in resistance either way from balance within the recording range.

The above arrangement provides for a working range up to 100,000 ω, which, with the external potential here recommended, we have found adequate for practically all subjects. For those few individuals above 100,000 ω the following modification may be employed. Switches may be provided in the b and d arms of the bridge for adding resistances of 10,000 ω and 100,000 ω, respectively, thus giving a 1 to 20 ratio and a 200,000 ω range in arm d of the bridge. For the exceptional conditions where a 200,000 ω range is required, the values in this circuit are such that doubling the applied voltage will keep the current through the X arm the same as it was with the 100,000 ω range.

The procedure with this resistance box is as follows: (*a*) the subject is excluded from the circuit by switch s; (*b*) the galvanometer is balanced by setting the X resistance at 100,000 ω; (*c*) a scale is recorded by adding and subtracting a series of 1,000 ω units from this value; (*d*) the galvanometer is shunted and the switch, *s*, is thrown, bringing the subject into the circuit; (*e*) the standard resistance is reduced by an amount equivalent to the subject's resistance while the shunt is gradually removed from the galvanometer. According to this procedure the subject's resistance at any time will equal 100,000 ω (or 200,000 ω) minus the resistance of the standard in series with him, plus or minus the value indicated by the recording galvanometer on the scale. This arrangement satisfies the following requirements for comparison of different subjects:

1. High sensitivity
2. Small current through the subject thus avoiding irritation
3. Practically uniform current through all subjects regardless of the subject's resistance
4. Continuous quantitative records
5. Records in standard units
6. Automatic balancing of the bridge
7. Stable balancing of the bridge with the subject out of the circuit
8. Uniform scale values, when desired, for subjects having different resistance levels.

REFERENCE

1. DARROW, C. W. Continuous quantitative records in standard units by the Wheatstone bridge method. *J. Gen. Psychol.*, 1930, **4**, 418-420.

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RELATIVELY NON-POLARIZING, CONSTANT MOISTURE, CONSTANT PRESSURE, CONSTANT AREA ELECTRODES[1]

CHESTER W. DARROW

Galvanic skin reflex studies comparing the resistances of different individuals are of little value without adequate control of the conditions at the electrodes. Non-polarizable electrodes of the liquid variety are often unsuitable either (*a*) because of difficulty in attaching the types representing constant area, or (*b*) because of the difficulty of controlling and keeping the area of immersion uniform for subjects with different sized hands in the case of the finger immersion types. Simple zinc sulphate, kaolin paste, zinc plate electrodes are objectionable for prolonged records (*a*) because of the drying of the paste, and (*b*) because of the differences in the sensitivity of the skin of different subjects to the zinc sulphate. Even when zinc sulphate of "physiological" concentration mixed with kaolin is employed, some subjects manifest cutaneous irritation. Contacts with the skin made with physiological saline obviate this difficulty. Saline alone, however, enormously increases the polarization and, therefore, the apparent

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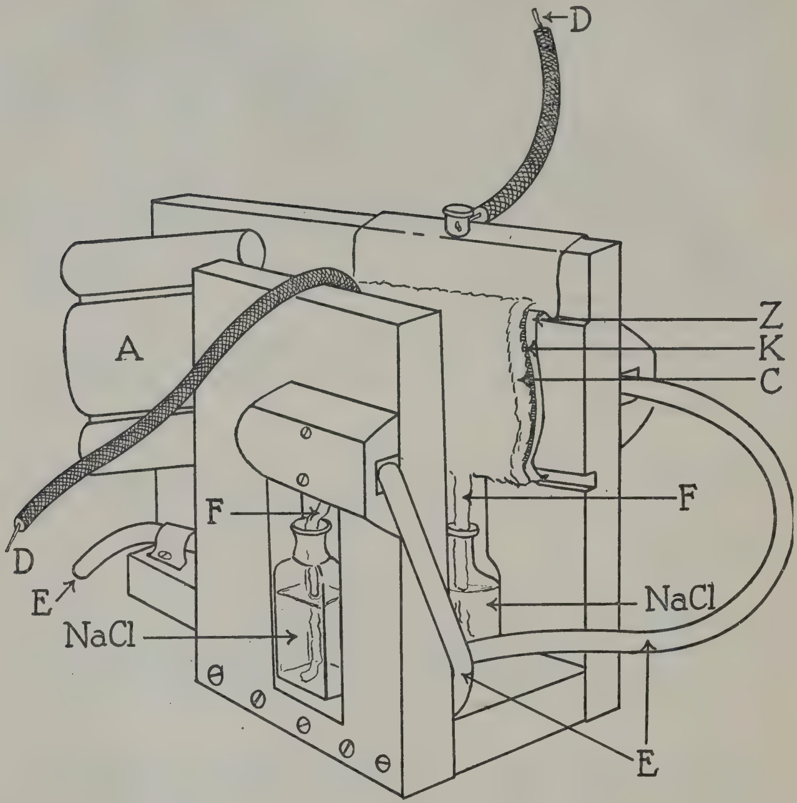
[1] Studies from the Behavior Research Fund and the Institute for Juvenile Research, Chicago. Series B, No. 181.

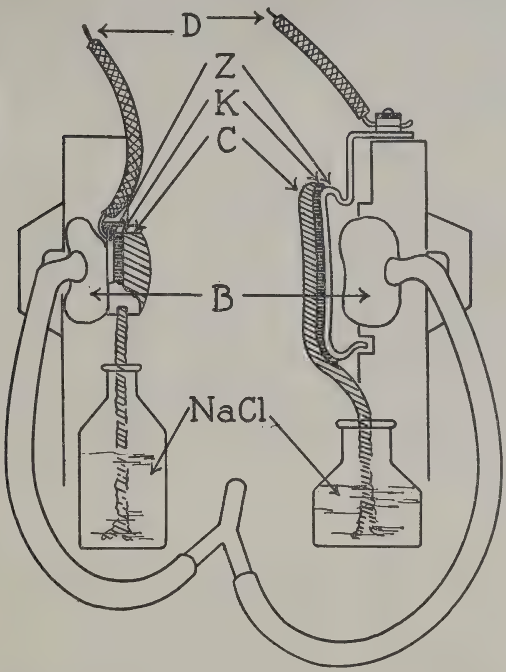


Relatively Non-Polarizing, Constant Moisture, Constant Pressure, Constant Area Electrodes

A, metal "glove" for finger rest.
B, balloons transmitting pressure to backs of electrodes (see diagram on following page).
C, absorbent cotton soaked with physiological saline.
D, leads to recording circuit.
E, tubes transmitting pressure to balloons.
F, absorbent cotton wick conducting physiological salt solution to electrodes.
K, saturated zinc sulphate kaolin-paste.
NaCl, physiological salt solution reservoirs.
Z, zinc plate electrodes.

resistance of the electrodes, no matter what metal is in contact with the electrolyte.

The electrode here described has proved fairly satisfactory and we are, therefore, offering it for use, criticism, or modification by those interested.



RELATIVELY NON-POLARIZING, CONSTANT MOISTURE, CONSTANT PRESSURE, CONSTANT AREA ELECTRODES

B, balloons transmitting pressure to backs of electrodes.
C, absorbent cotton soaked with physiological saline.
D, leads to recording circuit.
K, saturated zinc sulphate kaolin-paste.
NaCl, physiological salt solution reservoirs.
Z, zinc plate electrodes.

As evident from the illustrations, it consists of a combination of saturated zinc sulphate kaolin-paste on a zinc electrode, with a protecting layer of absorbent cotton soaked in physiological saline between the kaolin-paste and the skin. Absorption and drying of the saline is compensated by a supply led to the center of the cotton by a short absorbent cotton wick from reservoirs beneath the hand. Constant pressure of the respective electrodes against the hands is maintained by a head of water supplied from a rubber bag which can be raised to a fixed height after the subject's hand is in place. The pressure is transmitted through the balloons to the backs of the two electrodes.

The zinc plate of the small electrode is 1¼ inches in diameter, fitting, according to our first arrangement, a ring turned from a standard radio tube base. In a recent modification we have substituted for this composition ring the flexible rubber ring from a standard faucet filter into which the zinc plate fits conveniently. The pliable edge of this ring makes better contacts with uneven surfaces than were possible by the original arrangement. The other electrode presents to the back of the hand a surface 2 x 3¼ inches. The large area of this electrode and the fact that it is applied to a relatively inactive skin area insures that the recorded changes will be primarily those from the palm. The reduction of skin polarization by the application of iodine or by needle pricks through the skin underneath this electrode offer additional insurance that variations at this electrode do not contribute significantly to the recorded changes.

The arrangement here suggested provides an electrode which is relatively (*a*) easy to apply, (*b*) non-polarizable, (*c*) of constant pressure, (*d*) of constant area of contact, and (*e*) of constant moisture regardless of the drying or perspiring of the skin.

Behavior Research Fund
Chicago, Illinois

A STANDARDIZATION FOR AMPLIFIED RECORDS OF THE GALVANIC SKIN REFLEX[1]

Chester W. Darrow

A serious weakness of the techniques most frequently employed for registering the galvanic skin reflex by means of vacuum-tube amplification is the fact that these methods do not provide quantitative measurements in standard units (ohms) of the levels of apparent resistance, or of the changes in apparent resistance incidental to stimulation.[2] Although the Behavior Research resistance box, previously described (1) as a means of securing continuous quantitative records, may be used in the input of an amplifier, we have found a simpler method for use with vacuum-tube amplification.

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[1] Studies from the Behavior Research Fund and the Institute for Juvenile Research, Chicago. Series B, No. 174.

[2] For more or less obvious reasons, which we may not here enumerate in detail, resistance change is a function of the subject's resistance level. Furthermore, the magnitude of any deflection is a function of the relation of the subject's resistance level to the resistance of the external circuit with which he is connected. Even where an attempt is made to keep the current through the subject constant, the deflections from an individual with a changing level of resistance are of ambiguous significance, while the comparison of deflections from subjects with different levels of resistance is even more to be questioned.

The apparatus for standardization here proposed is very simple. A standardized variable high resistance[3] is placed in the input of the amplifier, as shown in Figure 1, with a switch by means of which the subject may be included in series with this resistance. The procedure with this arrangement is as follows: (*a*) The standard resistance set at some uniform value such as 100,000 ω is thrown into the circuit. (*b*) The amplifier, of compensating arrangement on the recording device, is adjusted to bring the indicator near the center of the recording range of the instrument. (*c*) The standard resistance is increased or decreased by successive additions or subtractions of some convenient standard unit, such as 1000 ohms, and the positions of the indicator registered, providing a scale for the entire recording range of the instrument. (*d*) The subject is thrown in the circuit and the series resistance is reduced sufficiently to bring the recording indicator on the scale. The scale value (standardized as above) now shown by the indicator, minus the resistance in series with the subject, gives the subject's resistance. When at any time the changes in the subject's resistance become so great as to carry the indicator beyond the recording range, compensation is afforded by adding or subtracting known values from the standard resistance in series with the subject.

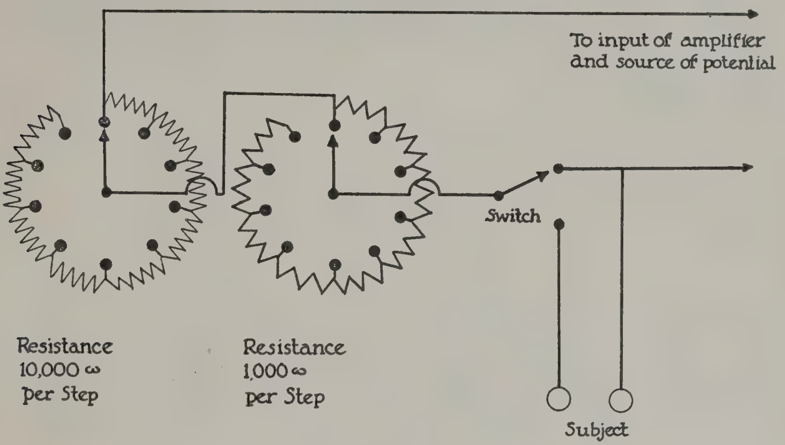

FIGURE 1

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[3] Where alternating or intermittent current is used in circuit with the subject, only resistances wound for alternating current may be employed as standards.

Of course, such a procedure presumes the use of an amplifier having stable characteristics.

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Behavior Research Fund
Chicago, Illinois

ELECTRICAL RESETTING DEVICES FOR THE DUNLAP CHRONOSCOPE

Erwin A. Esper

When the Dunlap chronoscope is used for measuring a long series of reaction times, the manual restoring of the hands to zero after each measurement results in undesirable delays and irregularities in the succession of stimulus presentations, and perhaps also in occasional inaccuracies in the resetting. In Figures 1 and 2 are shown two devices whereby the chronoscope may be reset to zero electrically by a pressure on a key.

Figure 1 shows a restoring device for the Model III chronoscope. Since this model lacks a revolution counter dial, only the large hand needs to be reset. The lever *SA-CL,* of No. 11 music wire, passes through an insulated bearing in the clamp block. The arm *CL* dips into a small mercury cup. The clamp block is of brass, the front jaw bevelled to clear the clock-hand, and the rear jaw fitted with a milled set-screw whereby the clamp can be fastened on the circumference of the dial. The brass bearing for the lever is contained in a bakelite piece screwed to the top of the clamp block, and a bakelite bracket screwed to the side carries the small brass plate on which are mounted the mercury cup and its binding post. The horizontal shaft which passes through the bearing, and whose forward end is bent to form the striker arm (*SA*), is 1¼″ in length; the horizontal arm whose bent end dips into the mercury cup is 13/16″ in length.

The device is used in conjunction with a 3-leaf key similar to the Dunlap master key, but the upper and lower leaf circuits are interchanged as compared with the stimulus-reaction arrangement; that is, the upper leaf is in the posterior magnet circuit and the lower leaf in the anterior magnet circuit. The resetting device is connected by its binding posts in series with the posterior magnet. Hence, when the dial hand is at any position other than zero, a pressure on the key closes the circuits, first, through the posterior magnet, and, secondly, through the anterior magnet; the hand

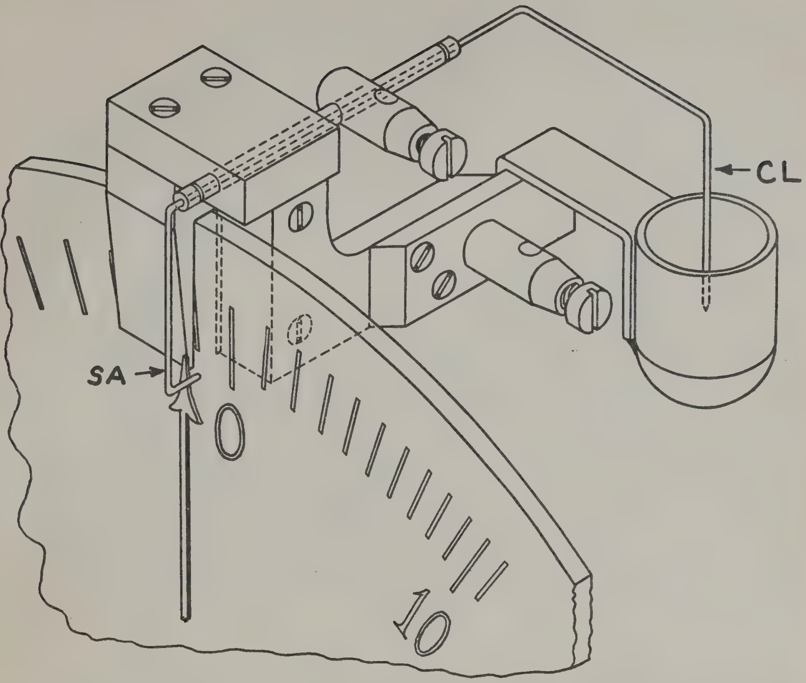

FIGURE 1

revolves until it strikes the striker arm, breaking the posterior magnet circuit at the mercury cup. By means of the clamp block the striker arm may be empirically adjusted to such a horizontal and vertical position as to stop the hand exactly at zero. The above wiring is independent of and in addition to the stimulus-reaction circuits, and in no way changes the operation of these circuits. The lightness of the wire lever obviates the possibility of jarring sufficient to cause armature "hunting." On the other hand, I have found that if gold or silver contacts are used instead of the mercury cup, the motor vibration jars such contacts very slightly, but sufficiently to cause clutch slippage and consequent armature "hunting." If it is found that the wire contact rides on the surface of the mercury instead of dipping into it, this same trouble will be experienced, and it will be necessary to fasten an adjustable weight, e.g., in the form of a few coils of light steel spring, to the mercury cup lever arm. It is also advantageous to sharpen the contact wire.

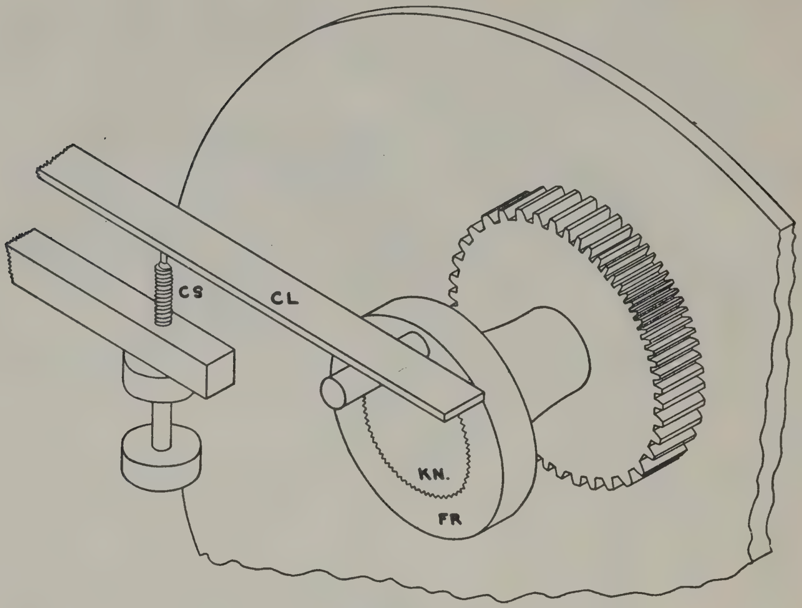

FIGURE 2

Figure 2 shows a resetting device for the Model II chronoscope, whereby both the large dial hand and the revolution counter may be restored to zero. Over the knurled knob *KN,* which is furnished with this model for manual resetting, is driven the fiber ring *FR* of 3/16″ thickness, bearing a small brass finger. As the revolution counter rotates, this finger lifts the lever *CL,* thereby breaking a contact at *CS.* The lever *CL* is 3¼″ in length; its bearing (not shown) is carried by a fiber post screwed to the chronoscope base. The contact screw *CS* permits of adjustment so that the contact will be broken at the exact instant when both hands arrive at zero. Platinum or gold contacts can be used in this case because the greater power available permits of heavier weighting of the lever. The wiring is the same as for the previously described device.

Both of the above devices have been in intensive use over periods of several months, and have been found to facilitate the smooth presentation of reaction series.

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Seattle, Washington

AN APPARATUS FOR REGULATING THE CONTACT TIME OF AN ELECTRIC CURRENT

Carroll A. Whitmer

In a recent experiment on form discrimination in the peripheral field of vision[1] the writer faced the problem of presenting two illuminated stimuli simultaneously, for a short duration of time. Mr. P. G. Exline of the Mellon Institute of Industrial Research suggested the possibility of using a Jolly balance spring to regulate the contact time of the circuit through the lamps which illuminate the stimuli. The apparatus described here was devised for that purpose and was found to be simple and efficient.

Figure 1 is a diagram of the apparatus. The magnet (*C*) was operated on a 10-volt current and attracted the plate (*D*) to which the contact point was fastened. When the magnet was released the contact point dropped into the mercury (*G*) and completed a circuit through the wires (*H*) which led from the source through the stimulus lamps. As the contact point was swung upward by means of the Jolly balance spring (*E*), the plate was caught by the magnet and held until the next presentation of the stimuli was desired. The release switch for the magnet, on the wires (*B*), was arranged in a location convenient for the experimenter.

The contact time of the circuit used in our experiment was measured by a Dunlap chronoscope, and for a series of 100 contacts made by the apparatus the average time of .376 seconds ranged from .366 to .390 seconds, with a standard deviation of .005 seconds. Frequent use of the apparatus over a period of several weeks did not change the time adjustment.

In our experiment a weak current was allowed to pass through the lamps continuously in order to keep the filaments heated and thus reduce the action time of the lamps. By means of this expedient the duration of the stimulus time was virtually equal to the contact time of the circuit through the timing apparatus.

The apparatus is inexpensive and easily set up. Minor changes in the relative distance of the spring and magnet above the mercury cup permit adjustment of the apparatus for different contact times.

University of Pittsburgh
Pittsburgh, Pennsylvania

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[1] Peripheral Form Discrimination under Dark Adaptation, manuscript in preparation.

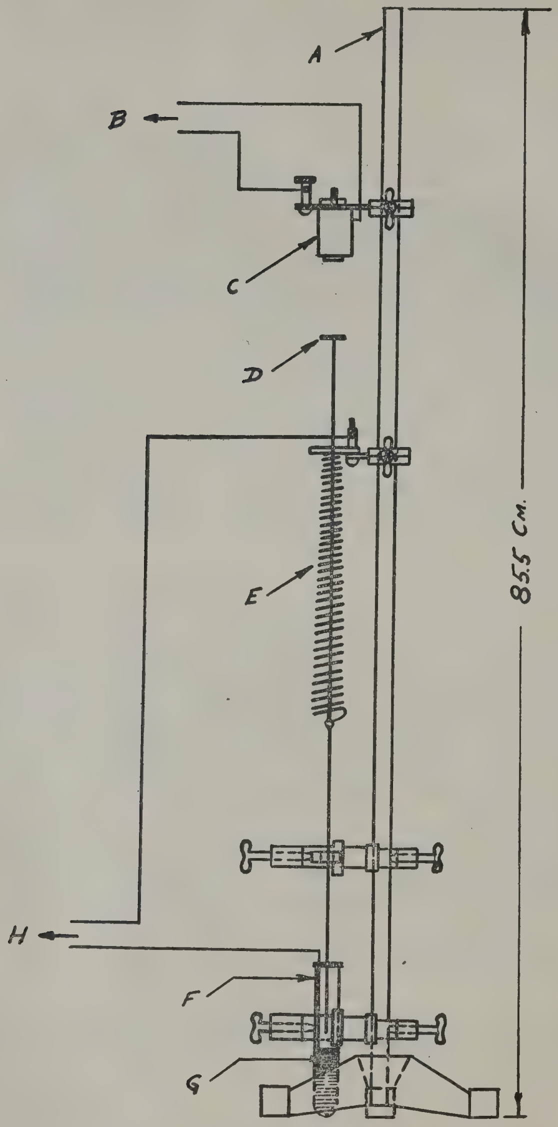
A
B
C
D
E
F
G
H
85.5 Cm.

FIGURE 1
Diagram of the Apparatus

SOME IMPROVEMENTS IN "A SELF-RECORDING MAZE WITH AN AUTOMATIC DELIVERY TABLE"[1]

JACK BUEL

In December, 1925, Tolman and Jeffress (1) gave a preliminary description of a form of self-recording maze "to be used in experiments in which a large number of animals are to be run." This article was followed by a report by Tolman, Tryon, and Jeffress (2) of the construction and operation of a modified form of such a maze with an automatic delivery table. This apparatus is being used by Tryon in his experiment on the inheritance of maze ability (3), and on individual differences in maze ability (4). The practicability of such a maze is indicated by the fact that up to April, 1931, when the alterations reported here were made, 1020 animals had been run on this apparatus, necessitating the automatic recording of 17,700 single maze runs.

When the maze was moved in 1930 from the old Psychology Building and reconstructed in new quarters, it was found that errors existed in the wiring diagrams as previously reported (2) of such a nature as possibly to confuse anyone who should attempt to reproduce the maze. It was found also that several improvements in the apparatus were required. These improvements, herewith reported, in no way change the experimental controls and handling of the animals in the inheritance problem still under way, nor do they alter the mechanics or pattern of the maze as previously reported.

A brief resume of the general procedure will clarify the description of the corrections and improvements.

The animals to be run are placed in a revolving delivery table. The table has two tiers of compartments so that each animal has an upper and lower compartment. He lives in the upper compartment until the time of the day's run, when he and his compartment are transferred to the lower tier. An animal is let into the maze through an opening in the side of the revolving delivery table. The floors in the various units of the maze are balanced on fulcra, so that when a rat steps on them they dip contact points into mercury cups located beneath the floors. These mercury contact points are wired to a recording voltmeter. As the rat traverses the maze, the successive contacts of the movable floors are indicated in terms of time and errors on the voltmeter tape. Two of the movable floors start or stop the motor which pulls the recording tape through the voltmeter. More complete diagrams can be found in the previous report referred to (2).

IMPROVEMENTS AND CORRECTIONS

One correction is concerned with the operation of the motor of the record-

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[1] The writer wishes to acknowledge his indebtedness to Professor R. C. Tryon for his cooperation and helpfulness in making the improvements.

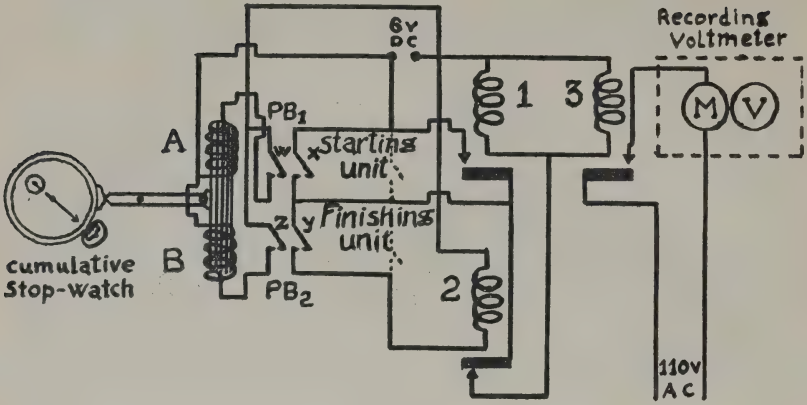
6V
DC
Recording
Voltmeter
M
V
1
3
PB1
A
w
x
starting
unit
Finishing
unit
z
y
B
cumulative
Stop-watch
PB2
2
110V
AC

FIGURE 1
Wiring Circuit Controlling Recording Motor and Stop-Watch

ing voltmeter [Figure 9 in the report referred to (2)]. The movable floor contacts (starting and finishing units) remain as reported. The wiring of the relays operating the motor is now as shown in Figure 1.

When the movable floor of the starting unit is depressed momentarily by the weight of the rat, relays *1* and *3* operate, one side of the current supply passing through the *closed* contact points of relay *2*. The closing of relay *1* shorts the starting unit contacts thus holding relays *1* and *3* closed after the rat has stepped off the starting unit. Relay *3* closes the circuit to the motor

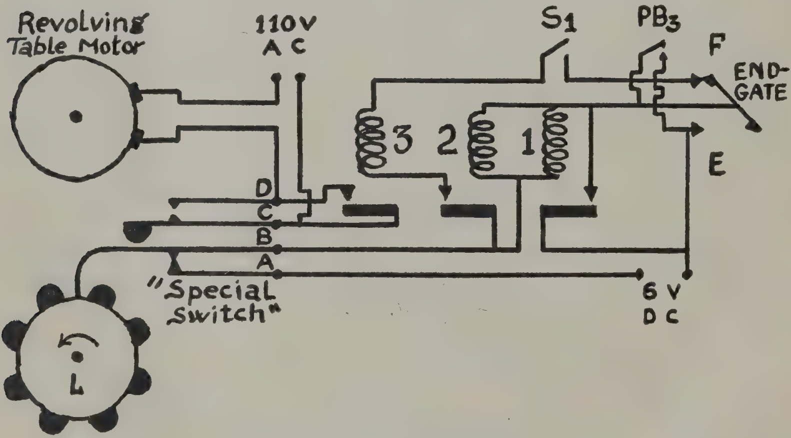
Revolving
Table Motor
110V
AC
S1
PB3
F
END-
GATE
3
2
1
E
D
C
B
A
"Special
Switch"
6 V
DC
L

FIGURE 2
Diagram of the New Arrangement for the Operation of the Delivery Table

of the recording voltmeter. When the rat momentarily depresses the finishing unit relay *2 opens*, releasing relays *1* and *3* and interrupting the current supply to the motor. All the relays are now released, ready for the next rat's run. As erroneously reported (2), relay *1* would not release when the finishing unit was depressed.

Two improvements have been added to the old recording system as follows. (1) PB_1 and PB_2 are double-pole push buttons located in a control box on the experimenter's desk. By pressing these buttons and making contact through x and y he may start or stop the recording voltmeter motor. This control enables the experimenter to stop the recorder in case a rat "stalls" in the maze, (2) the time during which the voltmeter is "off" during a run is taken by a solenoid-operated cumulative stop-watch constructed as described below. See Figures 3 and 4. The principal dimensions are as follows. The base is 3 5/8 inches wide and 6 inches long. The top is 1 inch wide by 6 inches long. The height is 5 5/16 inches. The maze control push buttons and switches are combined with the stop-watch control as indicated in the illustrations. Two coil forms, 1 1/2 inches long, 2 inches outside diameter, and 1/2 inch inside diameter were wound with number

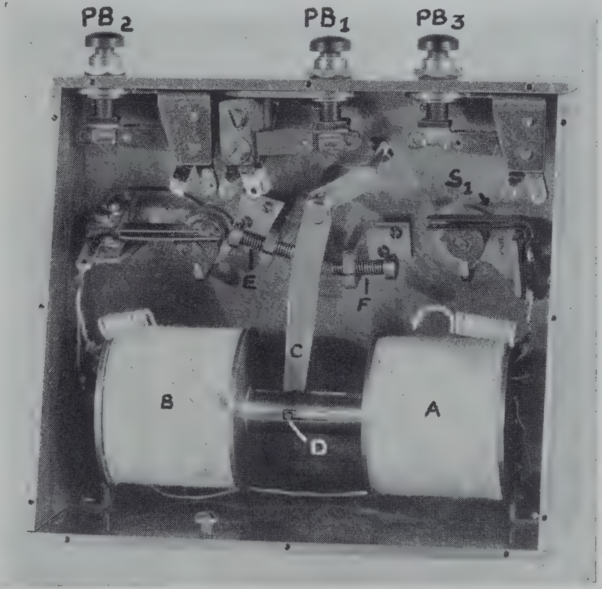

FIGURE 3
The Stop-Watch Control with the Back Removed

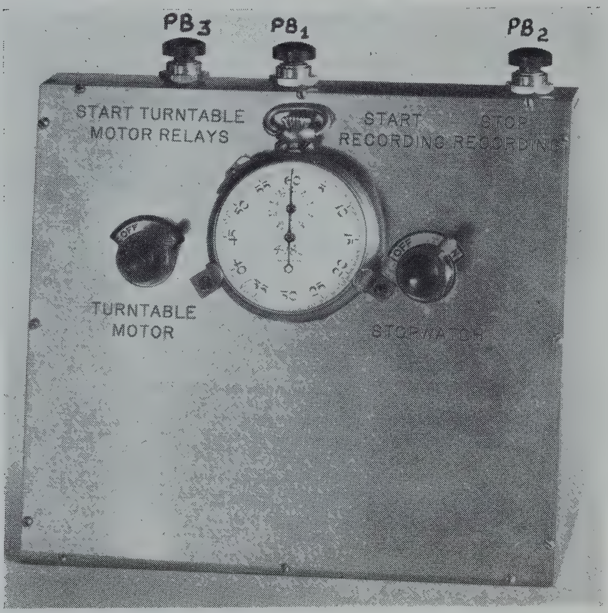

FIGURE 4
Front View Showing the Method of Clamping the Watch to the Box

22 D.C.C. magnet wire. These coils, *A* and *B*, were wound on the same hollow non-magnetic core, and separated from one another 1 1/2 inches. A 3/8-inch soft iron rod is inserted into the coil core, the fit being such that it slides back and forth with little friction. At the center of the soft iron core one end of a lever *C* is attached by a connecting pin *D*. The lever passes through a slit in the coil core. The fulcrum of the lever is 2 1/2 inches above the center of the soft iron core. The other arm of the lever is 5/8 inches long and has a rod riveted to it which projects through an over-size hole in the face of the housing. This rod is connected to the thumb control for starting or stopping a cumulative stop-watch. The watch is fastened by clamps to the face of the box. Any cumulative stop-watch having a sliding thumb control on its perimeter can be attached. The two set screws, *E* and *F* in Figure 3, are adjusted to prevent the lever from swinging too far. By this arrangement the shock of stopping the movement of the core and lever is taken by the set screws rather than by the watch thumb control.[2]

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[2] This piece of apparatus can be used in many experiments where measurements of cumulative time are taken by a stop-watch. Since it has this general use duplicates (with or without the switches) may be desired. The stop-watch control can be supplied by the Western Electro-Mechanical Co. of Oakland, California.

The construction of the watch control is schematically diagrammed in Figure 1.

Referring to Figure 1, when push button PB_2 is pressed the recording volmeter motor stops as described above. At the same time, however, contact points *z* of PB_2 close, thus connecting the stop-watch solenoid *B* with the 6-volt current supply. The iron core is pulled to that side (*B*) and the lever system connected to the core moves the thumb control on the stop-watch to the starting position. When the starting unit button PB_1 is pressed, the recording motor starts, and at the same time, through contacts *w* of the push button, coil *A* of the stop-watch solenoid is connected to the 6-volt current supply. The core is pulled to that side (*A*) causing the stop-watch thumb control to move to the stop position. The time the motor has not been running is therefore automatically recorded. This is especially convenient during the early stages of learning when rats are likely to stall in the maze since the recording motor does not have to run continuously over a long period when there is no record being taken. The error present in taking a record of this time lapse by hand is removed.

A major improvement in the apparatus concerns the wiring of the relays involved in the operation of the delivery table. The table operation is controlled by the end-gate in the maze which has the same form as in the previous report (2). A brief resume of its operation will clarify its use. The end-gate, made of hardware cloth, hinges at the bottom and rests normally at an angle of 45°. It is a duplicate of other gates placed in the maze to prevent retracing. The rat steps off the last section of the maze upon the end-gate, which lowers to a horizontal position under his weight, and then he goes into his home cage (upper compartment) on the living table. As he steps off the gate, thus allowing the latter to swing up again, the table begins to revolve very slowly by means of a motor and spider which engages pegs on the under side of the periphery of the table. This places the turn-table in such a position that the next rat may enter the maze from the next lower compartment.

The end-gate has a double set of contact points, the purpose of which is to make sure that the rat has got off the gate and onto the table before the table starts moving. If, upon the first contact (*E*, Figure 2) when the gate is depressed, the table started, the animal might be caught either not on the table at all, or half on and half off. By means of the relays the connections are so arranged that contact must be made *first* at *E* (gate depressed) and *then* at *F* (gate released to its former position by the rat's stepping off and into his table compartment) before the table starts to move.

As originally wired, the operation of the table was faulty in the respect that occasionally the table would begin to revolve with the first depression of the end-gate. This was due to the fact that momentarily the current operating relays *1* and *2* had to go through the coil of relay *3* *before* the end-gate returned to its original position. The correct operation of the maze, as previously reported (2), depended upon a nicety of adjustment of resistances of connecting wires and relays that was not conducive to a reliable operation of the maze. Therefore, a new arrangement of relays has been made though the "special switch" on the turn-table spider, as well as the end-gate of the maze, is still used. Figure 2 shows the improved arrangement.

The end-gate always makes contact at *F* until a rat depresses it, when contact with *E* is made instead of *F*. When contact is made at *E*, relays *1* and *2* close (the current passing through *A* and *B* of the "special switch"), but relay *3* remains open, since one terminal of its solenoid is connected to *F*, now open. The other terminal of the coil of relay *3* is connected through the "special switch" (*A, B*) to the current supply by relay *2*, now automatically held closely by relay *1*, irrespective of the position of the end-gate. When the end-gate is released to its normal position by the rat stepping onto the table, contact is made at *F*, thus closing relay *3* which starts the turn-table motor. The 110-volt current supplied to the motor also goes through the "special switch" as indicated (*C, D*), as well as through the contact points of relay *3*.

As the table revolves, contact at the points of *D* and *C* is made, and *after* this has occurred, contact *A-B* is broken, thus releasing all the relays. The turn-table continues to revolve, however, since the current supply to the motor is now through the contact points *C* and *D* of the "special switch." When the opening in the turn-table compartment for the next rat is opposite the maze entrance, contact between *C* and *D* is broken (the lever arm of the "special switch" falling off a nub on *L*), and the table ceases to revolve until the rat just entering traverses the maze and operates the end-gate, when the table again revolves and allows the next rat to enter the maze.

Another improvement is PB_3, a push-button, and S_1, a switch in the control box on the experimenter's desk. Pushing the button PB_3 starts the table revolving, while the switch S_1 controls relay *3*, and hence the turn-table motor until contact is made at *D* and *C* of the "special switch" when a master switch on the 110-volt supply must be opened to stop the table.

It sometimes happens that a rat's tail may get caught between his compartment and the sides of the table, or in the entrance and exit openings, so that the switches mentioned are in the nature of emergency controls.

Finally, a further new feature is the portable control box on the experimenter's desk. It has a seven-wire connecting cable attached which plugs into the table, or into other receptacle sockets located at convenient places about the maze room. The receptacle sockets carry the circuits controlling PB_1, PB_2, PB_3, and S_1. The control box may thus be moved about to any convenient position for surveying and controlling the maze during its operation. This improvement has been found to be very useful.

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Berkeley, California

A CONTINUOUSLY VARIABLE SPEED POLYGRAPH WITH A TELECHRONIC TIME MARKER[1]

Jack Buel

The polygraph described below was designed to meet the requirements of: (1) simplicity and reliability; (2) a continuous and wide range of paper speeds; (3) a built-in self-inking time and stimulus marker of great accuracy and reliability; (4) a high degree of flexibility and utility for a variety of laboratory uses; and (5) a low first cost and economical operation.

The completed instrument (Figure 1) without attachments is 14 inches long, 8¼ inches wide, and 7¼ inches high. It weighs but 14½ pounds, and, with a cover supplied with a handle, is quite portable. All the construction except the base-board is metal. The apparatus operates on 110 volts 60-cycle A.C., while the stimulus and time markers are used with an external 6-volt D.C. supply.

The paper used with the polygraph is an inexpensive adding machine type which can be obtained up to five-inch widths. The polygraph utilizes any width up to five inches. The roll of paper is inserted at *A* and held in place by a pin *B* under spring tension. The paper is threaded over a roller and through a slit in the top of the polygraph. Five and one-half inches from this first slit is another through which the paper leaves the recording platform and passes over a roller and then between two metal rollers held together under spring tension. The lower of these two rollers, *C*, is the motivating or paper-drive roller. The upper roller, *D*, idles on the lower roller and is held against it by a spring. This roller is cut up into small segments so that irregularities in the paper surface or the use of paper less than five inches in width will have an evenly distributed pressure over the entire surface. These rollers have finely corrugated surfaces. This method of driving the paper is more desirable than the usual one employing rubber rollers since the latter tend to become glazed and hard after considerable use and allow the paper to slip.

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[1] This instrument can be supplied by the Western Electro-Mechanical Co. of Oakland, California, complete as described for $250.00.

This apparatus was built for a research project under the direction of Professor F. L. Kleeberger of the Department of Physical Education, University of California.

The paper is held in place on the recording platform by a movable plate, *E,* which has a groove cut into its under side so that part of the plate covers the edge of the paper and holds it flat against the surface of the recording platform. A small groove in the recording platform, into which a key in the movable plate fits, insures the correct alignment of the paper with the plate.

At one edge of the recording platform are two self-inking pens, *F* and *G,* and the ink reservoir, *H.* The pens are the Bristol type and require no attention as long as there is a supply of ink in the adequately large reservoir. The pens are readily pulled from their sockets for cleaning or storage, being held in place by a small flat spring inserted into a slot. Pen *G* is the time marker. This pen is moved by a 6-volt D.C. magnet located under the recording platform. The time interval is obtained by the use of a Telechron motor which drives a wheel, *I,* having tapped holes about its circumference. Five pegs are supplied which screw into these holes. Two pegs are seen in the wheel, while the extra pegs are screwed into the polygraph housing at *J* when not in use. The pegs, when screwed into the wheel, pro-

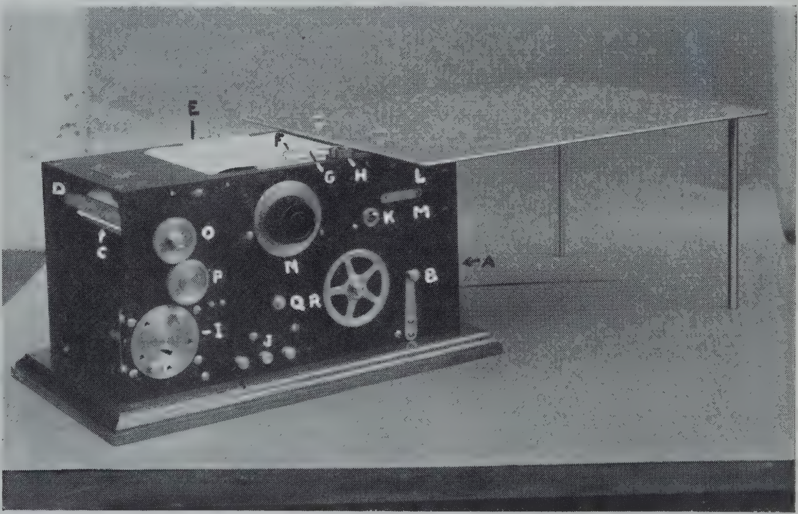

FIGURE 1
Polygraph with Instrument Board Attached

ject inside far enough to push two contact points together when the wheel turns, thus closing the circuit to the time-marker magnet. Since the wheel makes one revolution per second, time intervals of one second, five-tenths second, and two-tenths seconds may be obtained by properly spacing the pegs about the circumference of the wheel. Switch *K* breaks the circuit to the time marker when it is not wanted.

The other pen, *F,* is the stimulus marker. A key or other circuit closer across the binding posts *L* and *M* closes the circuit to the motivating 6-volt D.C. magnet.

The speed of the paper is calibrated directly on the dial, *N,* in terms of inches per minute. The usual methods of changing speeds in polygraphs are: (1) by changing gear ratios; (2) by using a series-wound motor with a variable resistance in series; or (3) by a combination of both the above methods. The first method is expensive and does not allow for a continuous gradation of speeds unless some sort of friction drive is employed. The second method has heretofore been faulty in that as the resistance in series with the motor is increased with the consequent slowing down of the motor, the torque decreases causing uneven motor speeds. Also slight changes in the load on the motor at the slower speeds cause marked changes in the paper speed. The system employed here is designed to keep the torque constant, irrespective of the motor speed.[2]

A 200-ohm variable resistance is in series with the motor input, and a 200-ohm resistance is shunted across the armature. These two resistances are varied inversely, and are controlled by the same knob and shaft, *N.* As the resistance in series is increased with the consequent slowing down of the motor, the shunt resistance is decreased, thus holding the wattage of the motor constant. Without any other changes than turning the knob, continuous paper speeds of two inches per minute to thirty inches per minute may be obtained. By removing gears *O* and *P* and replacing them with gears *Q* and *R* on their storage pins, a ratio of one-tenth the above speeds may be obtained, i.e., a paper speed range of two-tenths of an inch per minute to three inches per minute. The paper speeds respond at once to changes of the control knob (due to the constancy of torque), thus allowing changes of speed over a wide range during a recording without stopping the polygraph. The flexibility and convenience of this control will be appreciated by those who have used a gear-shifting type of recorder.

There is a minimum of exposed gears. The reduction gears are built directly into the motor housing and are enclosed.

A combined animal and instrument board attaches to the top of the polygraph. This board is made of non-tarnishable metal, with tapped holes spaced at one-inch intervals. Rods, clamps, or other apparatus may be screwed into this board for holding recording instruments. The dimensions of the board are 1/8 x 12 x 15 inches. It is supported at its free end by two metal legs.

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[2] I am indebted to the Western Electric Co. for the system used here.

The present polygraph has several advantages over the polygraphs with which the author is familiar. (1) The built-in time marker, (2) stimulus marker, (3) wide range of speed, (4) ease of control, (5) small dimensions and weight, and (6) low cost, make it particularly adapted to general laboratory use.

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A NEW CONTROL KEY

Roy M. Dorcus

In many forms of psychological experimentation it is necessary to have the apparatus so arranged that the rapidity or slowness of the reactor will not seriously interfere with the mechanical operation of the instrument. Further, in some types of apparatus, the length of time that the reactor keeps the key depressed seriously interferes with the actual operation of the set up. If a circuit is to be momentarily established and then broken with the ordinary control key, the subject must be given instructions to make his reaction quickly and then remove his finger from the key. This procedure works satisfactorily in some types of work and with some types of apparatus but in others failure on the part of the subject to follow instructions will cause the expenditure of much time in training new subjects and invalidate results that have been secured through considerable labor. The key which has been devised eliminates some of the difficulties in experimentation which have been mentioned. In actual operation, it does not make any difference how long the key is held down and the rapidity or slowness of reaction can be taken care of by the relative proportion of the brass and bakelite in the commutator. In designing the key, ease of operation, amount of throw, and possible modifications have been taken into consideration. If two com-

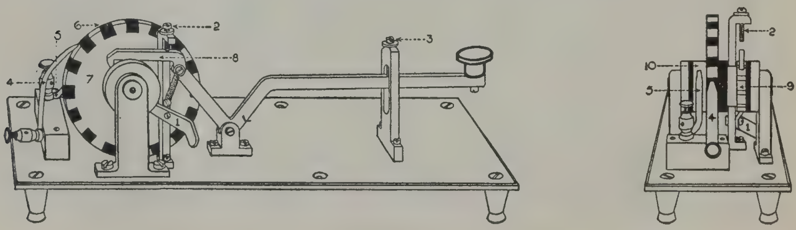

FIGURE 1

mutators of bakelite and brass are substituted for the commutator and collecting ring, a wide range of time intervals for closing the circuits can be secured, since they may be rotated independently of each other. The same effect may be produced by using two brushes on the single commutator. These would have to be arranged in such a way that one of the brushes may be advanced or retarded with respect to the other.

1. Stop operating on ratchet wheel which prevents the commutator from turning backward.

2. Adjustable stop which locks the commutator when it has turned the correct number of degrees. This prevents the commutator from going further under its own momentum when a quick reaction is made.

3. Adjustable stop which controls the excursion of the ratchet.

4 and 5. Commutator brushes. Two commutator brushes are used since the commutator is insulated from the rest of the mounting, thereby preventing the reactor from getting shocked.

6. Bakelite insert. These inserts serve as the dead points on the commutator.

7. Commutator made of brass with bakelite inserts.

8. Ratchet arm which engages the ratchet gear because of its own weight.

9. Ratchet gear. The number of teeth corresponds to the number of live points on the commutator.

10. Solid brass hub turned in one piece with the commutator. This serves as collecting ring to lead the current into the commutator.

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